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Unpacking the Sustainability of Meal Kit Delivery: A Comparative Analysis of Energy Use, Carbon Emissions, and Related Costs for Meal Kit Services and Grocery Stores

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Unpacking the Sustainability of Meal Kit Delivery:
A Comparative Analysis of Energy Use, Carbon Emissions, and Related Costs for Meal Kit Services and Grocery Stores

by

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Abstract

Unpacking the Sustainability of Meal Kit Delivery: A Comparative Analysis of Energy Use, Carbon Emissions, and Related Costs for Meal Kit Services and Grocery Stores

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According to the EPA, food waste represents the largest single share of landfilled municipal solid waste in the United States, followed closely by plastics and paper products (EPA, 2016). These materials are a staple of the food distribution industry. Their use, recycling, and disposal all contribute to energy waste and carbon emissions. Meal Kit Delivery (MK) services claim to play a role in reducing food waste by delivering pre-portioned ingredients for home-cooked meals to residential customers, who then use recipe cards to prepare meals in their own homes (Peters, 2016). However, smaller food portions and direct-to-door delivery may increase the overall packaging used per meal, and other components of the supply chain may also impact the environmental footprint of MK services.

This study seeks to quantify the differences in energy use and emissions—and their related costs— between MK services and traditional grocery stores. An average MK

service meal is compared to a meal prepared using the same ingredients purchased from a grocery outlet. Energy use and emissions are evaluated in five categories: building, last mile transportation, product packaging, food waste, and end of life material management. The economic impact of each model is evaluated based on estimated energy and emissions costs. Each variable is quantified using a combination of meta-analysis, direct measurement, and probabilistic analysis.

On average the MK service scenario used 20% less energy and generated 4% less emissions than the grocery-equivalent scenario. These savings amounted to an energy and emission cost savings of around 33%. In addition, MK services generated around 3.7 more pounds of packaging material per meal. These findings suggest that companies in both industries have opportunities to reduce environmental impacts and costs by improving the efficiency of their supply chains and developing creative solutions to address top energy use and emission sources.

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Introduction and Background

The U.S. Environmental Protection Agency (EPA) releases data on the characteristics of the Municipal Solid Waste System on an annual basis to track progress towards sustainable waste management goals. Data over the last 30 years shows that food and packaging waste—including plastics, cardboard, glass, and other materials—make up the highest share of waste that ends up in United States (US) landfills (EPA, 2016). While progress has been made towards increasing recycling rates for some materials—like paper and paperboard which is now recycled 75% of the time—the total volume of materials still being produced and ultimately entering landfills is substantial (EPA, 2016). For example, in 2014 (the most recent year data is available) Americans generated 38.4 million tons of food waste, which equals around 240 pounds per person per year.[1] If you include the 76.6 million tons of container and packaging materials[2] sent to waste management facilities each year, annual per capita waste rises to 720 pounds (EPA, 2016).

The economic and environmental consequences of this wasted material is significant. A study published in the International Journal on Food System Dynamics in 2012 estimated that the value of wasted food in the United States is around $198 billion, with around 63% of value lost at the consumer level and 37% during the distribution and retail sales process (Venkat, 2011). The same study estimates the greenhouse gas emissions associated with wasted food is around 112 million metric tons per year. According to Ernst and Young, the market size of the Containers and Packaging industry in North America is around $108 billion, which is significant because around 51% of the industry serves the food end market (Niel-Boss & Brooks, 2013). Other related sectors—

[1] Based on US population during the year of measurement (2014)
[2] Includes all packaging and container materials, which includes items not related to the food system.

like energy and manufacturing—further contribute to wasted resources. For example, a 2010 study by Cuellar and Webber found the amount of energy used to produce food that is ultimately wasted equals around 2% of the total energy used in the US per year (Cuellar & Webber, 2010). This wasted energy has an economic value of around $24 billion, and is responsible for releasing an estimated 112 million metric tons of carbon dioxide (EIA, 2017).

These statistics point to a systematic and challenging problem in the food sector. Over the past several decades, companies operating in this industry have sought solutions to pre-consumer waste, focusing primarily on incremental changes to reduce operational overhead in a thin margin business. However, new trends—like home delivery— suggest more substantial innovations are on the horizon. Meal Kit Delivery services— like Blue Apron and Hello Fresh— have taken the traditional activity of grocery shopping for home meal preparation and replaced it with a delivery and subscription-based business model. This grocery-store alternative claims to play a role in reducing food waste by controlling portions, but it may come at a cost (Peters, 2016). Meal kits tend to be package-heavy because the precise amounts of food needed to prepare each meal are individually packaged and the items are shipped to homes using delivery boxes and ice packs to preserve freshness. This study explores the tradeoffs between food waste, packaging waste, and other sources of environmental impact in the grocery industry by using an average meal kit delivery meal to compare the energy use, emissions, and lost economic value of a Meal Kit Delivery (MK) service with a traditional retail grocery store. While other alternatives to MK services—like visiting a restaurant or ordering takeout—are not evaluated in this study, the analysis framework presented here can be applied to alternative food service models as better data becomes available.

FOOD WASTE AND PACKAGING NEXUS

For decades, food suppliers have weighed the costs and benefits of packaging in their supply chains. Advances in packaging techniques have led to a reduction in food loss throughout the supply chain – from the distribution process, to retail stores and within households. Reductions in food loss due to improved packaging often results in an increase in packaging waste. Food manufacturers, distributers and retailers keep close tabs on the economics of this tradeoff when making business decisions. For example, a company may decide to opt out of using a better packaging technique if the economic benefit of reduced product waste does not outweigh the costs of the new packaging material. Similarly, many companies have opted against using more "sustainable" packaging materials (like biodegradable cartons), arguing their use can result in more food spoilage which is ultimately worse for the planet. A study by Franklin Associates conducted for the American Chemistry Council and the Canadian Plastics Industry Association concluded that using biodegradable packaging in lieu of plastics increased total emissions by as much as 130%, driven primarily by the recycling and reuse potential of plastic packaging and methane emissions from landfilled biodegrade packaging (Franklin Associates, 2014).

Other studies have explored the same issue from a different perspective. While food packaging plays a role in how food is moved and preserved in the process, it can also shape portion sizes and ingredient mix. For example, pre-packaged meals that are either fully or partially prepared combine a range of ingredients into one package that serves as a full meal. Hanssen, O.J. et al. completed a life cycle analysis of three meal types: Ready to Eat, Semi-Prepared, and Fresh Ingredients at Home. The findings showed that Ready to Eat meals had the most packaging, but resulted in the least amount of food waste. Even given this, Ready to Eat meals still had the highest amount of energy use and carbon emissions. Semi-prepared meals had the least amount of energy use and emissions, but were on par with using fresh ingredients at home (Hanssen, 2015). These studies illustrate that a reduction in food or packaging waste does not always result in a net decrease in environmental impacts and resource consumption. Thus, when claiming the benefits of a food supply chain strategy that reduces either food or packaging waste, it is critical to consider waste of all forms and their related environmental impact.

ENVIRONMENTAL IMPACTS

Overuse of natural resources has become an increasing concern for scientists and policy makers over the past several decades. As the GDP of industrialized countries like the US and those in Western Europe has grown, so has quality of life and disposable income. While the benefits of this trend are numerous—like improved health care, public safety, and income equality—it comes with tradeoffs. A countries volume of waste is highly correlated with economic development. Member countries of the OECD—a consortium of countries with predominately advanced economies— generate 44% of the waste worldwide, while only making up 13.5% of the world population (Bhada-Tata & Hoornweg, 2015). In the United States, waste is a regular part of daily life. Americans generate around 4.4 pounds of waste per day, up nearly 2 pounds since the EPA began tracking municipal solid waste generation in 1960 (EPA, 2016). More advanced economies also have more disposal options, including recycling. Since 1960, recycling rates in the US increased from 6.4% to 34.6% in 2014 and growing (EPA, 2016).

A significant portion of this waste generation can be traced back to our food and the materials we use to package, ship, and store it. The process of bringing food to the table in the US involves a complex and energy intensive supply chain often spanning the entire nation. A researcher at Iowa State University found that the ingredients in a single-serve yogurt travel 2,216 miles before the finished product reaches the consumer's hands (Pirog & Benjamin, 2005). Energy, water and other resources are used as the ingredients travel through the supply chain, starting at the farm where most food products originate. Table 1 summarizes the sources of greenhouse gas emissions and food loss throughout the typical food supply chain. Energy is used to power industrial and farming equipment, buildings, refrigeration, transportation, and disposal, and is predominately derived from fossil fuels, which produce carbon emissions that contribute to climate change. In addition, the use of fertilizer and refrigerants and the overall raising of livestock for food purposes releases additional non-energy emissions that further exacerbate environmental impacts. Pollution attributed to agricultural runoff can also damage freshwater systems, while soil erosion and nutrient depletion can impact the long-term viability of land for farming (EPA, 2015). When edible food is discarded throughout the supply chain, the resources used to grow, process, and distribute it— and the negative externalities they create— are also wasted.

Food loss can occur at every phase of the supply chain and can be difficult to accurately measure. One challenge is separating types of unavoidable food waste—like food that is lost in the process of cooking, other natural shrinkage, and from mold or pests— and avoidable food waste due to spoilage in the household or plate waste. The USDA defines overall food waste as 'food loss.' A subset of 'food loss' is 'food waste,' which occurs when edible items are discarded for cosmetic reasons or overpreperation. The distinction highlights the difference between food that should be discarded—like molded fruit that could make someone sick—and food that is suitable to consume. Because categorizing food waste is difficult, the USDA and the UN Food and Agriculture Organization publish data on food loss and differentiate between food waste and loss only when possible.[3] Nonetheless, the amount of food lost each year is well beyond what is necessary to protect public health. Other causes of food loss at each phase of the supply chain are shown in Table 1. Controllable factors like overpreperation, impulse purchases, label date confusion, and overstocking dominate food loss at the retail and customer levels, while mishandling, poor demand planning, and culling lead to losses when farming, processing, packaging, and distributing food (Gunders, 2012).

GHG Sources (1)	**Process** (2)	**Causes of Edible Food Waste** (3)
- Equipment Energy - Fertilizer	**Farming and Harvesting (24%)**	- Environmental damage - Market forces make harvesting uneconomical - Labor shortage - Overproduction
- Building Energy - Refrigeration - Packaging production	**Processing and Packaging (4%)**	- Culling based on quality or appearance - Improper storage or handling leading to spoilage - Trimming - Manufacturing processes
- Transportation Energy - Building energy - Refrigeration - Disposal (landfilling)	**Distribution *(included in retail)***	- Inconsistent refrigeration - Import delays - Rejected shipments
- Transportation energy - Building energy - Refrigeration - Disposal (landfilling)	**Retail (12%)**	- Overstocking - Lack of flexibility in order size - Ready-made food goes unsold - Sell by date passes - Outdate or unpopular items
- Transportation energy - Disposal (landfilling)	**Customer (35%)**	- Low consequences for waste - Label date confusion - Spoilage - Impulse purchases - Poor meal planning - Overpreperation

Table 1: Greenhouse gas emission and edible food waste sources by supply chain phase. Average food waste rates for each phase are shown in parenthesis.
Sources: (1) EPA, 2015 (2) FAO-UN, 2011 (3) Gunders, 2012

[3] For example, USDA data excludes inedible portions of food like animal bones and portions of plants that do not make it to the consumer.

Enhanced food packaging has long been used as a tool to combat food loss from the farm to the retail level. In many cases, it can be an environmentally effective strategy for preventing spoilage and extending the shelf life of products. Packaging is also used for other reasons, for example to enhance the convenience of product use or to differentiate the brand against competitors. While there is little doubt that packaging plays an important role in minimizing food waste, it is important to consider the impact of packaging production when discussing the overall environmental benefits of packaging as a tool to prevent food waste. Packaging materials like plastic and glass uses energy and water in the production process. Paper products like cartons and boxes use energy and water resources, while also reducing the amount of forest carbon storage available due to deforestation.

ECONOMIC IMPACTS

Environmental impacts can also lead to economic impacts. Carbon emissions cause public health issues like asthma, heat related deaths, and the spread of infectious disease (APHA, 2011). While these impacts are significant, the indirect costs of health care are far removed from the daily purchase of food. Customers experience more direct economic impacts when food is wasted, however. The USDA estimates that $114 billion worth of food is wasted at the customer level each year (USDA ERS, 2014). This does not include the estimated $1.3 billion it costs to landfill food waste each year (USDA ERS, 2014). Both costs represent customer dollars spent on unused products. The retail cost of uneaten food per household can be up $2,200 per household per year (Wilkes-Edrington, 2013). Simultaneously, an estimated 15.8 million households in the US are food insecure (Feeding America, n.d.). Thus, at the household level the food system represents a misallocation of financial resources that exacerbates food poverty.

Businesses operating in the food sector are not immune from the financial impacts of food waste. Food waste in the supply chain has a direct effect on company profits, as grocery stores cannot sell food that never makes it to the retail counter or spoils on arrival. The retail environment, where around 12% of food is wasted, represents a significant opportunity for improvement. The USDA estimates $46.7 billion worth of food is wasted at the retail level annually (USDA ERS, 2014). Some companies have already acted to capture this lost value. When the regional grocery chain Stop and Shop/Landover evaluated food losses in its produce department and took actions to prevent it—like reducing the mix of product offerings and cutting down on the amount of produce displayed—they saved around $100 million annually (Gunder, n.d.). Profits are also lost when companies spend money on real estate and electricity to operate grocery stores. Grocery and convenience stores have the highest Energy Use Intensity[4] of any commercial property type (Energy Star, 2014), and much of that energy is directed towards products that spoil or go unsold. Businesses also have reason to care about food waste at the household level. A study by the Shelton Group found that 39% of Americans felt the most 'green guilt' for wasting food, compared with 27% for wasting water and 21% for not recycling (Shelton Group, 2012). Customers also care about making bargain purchases; a study conducted by Strategy& found that 61% of grocery shoppers always seek discounts (Hodsori, 2012). Food waste inhibits retailer's ability to pass along discounts to customers. Produce, for example, has the highest markup of any grocery store item because of the high spoilage rate (Crowe, 2011). Thus, by reducing food waste throughout the supply chain grocery retailers can take more control over product pricing and offer strategic discounts to drive up profit margins.

[4] Energy Use Intensity (EUI) is the annual energy used per square foot of building space.

While the economic factors described here are nuanced and do not always result in direct costs savings to both customers and businesses, there is significant opportunity to reduce unnecessary economic costs by eliminating, at minimum, wasted energy throughout the grocery supply chain.

TRENDS IN THE GROCERY SECTOR

Customer behavior is beginning to address some of the economic and environmental factors discussed above, while also creating new impacts. Overall, trips to the grocery store have declined, which could lead to less vehicle miles traveled and subsequently gasoline and carbon emissions associated with operating motor vehicles. The average trips to the grocery store per week was 1.6 in 2016, compared to 2.2 in 2005 (FMI, 2016). Online grocery shopping has also increased – between 2015 and 2016 the portion of shoppers using online retailers for some of their grocery shopping needs rose by 4% to a total of 20% (FMI, 2016). Online shopping can reduce the miles traveled per item (because of optimized delivery routes) and eliminate the need for energy intensive grocery stores in every neighborhood.

Despite this trend, in-store shopping still dominates the retail grocery sector, with 74% of shoppers using supermarkets or supercenters as their primary shopping channel (FMI, 2016). Grocery store footprints have also grown over the past two decades. In 1995, the median grocery store was 37,200 square feet (FMI, n.d.). By 2016 the median size had risen to 42,000 square feet, with the average store carrying almost 40,000 unique items (FMI, n.d.). Interestingly, an individual grocery store customer purchases less than 1% of available products over the course of a year according to a study by Catalina Marketing (Marketing Charts, 2014). The tendency of customers to purchase the same products repeatedly may be why during this same period smaller stores with less variety have emerged and grown. Trader Joes, for example, stocks only about 4,000 items and has estimated sales that rival Whole Foods (Kowitt, 2010). Whole Foods itself is rolling out smaller stores—called 365—that have a smaller footprint and stock less items than their traditional store (‘About 365’, n.d.). This contradictory trend shows that consumers are finding a place in their shopping habits for different product mix offerings, which could be a positive for the economy and the environment. Smaller stores mean less building energy use and less product offerings can help eliminate wasted food from spoilage.

MEAL KIT DELIVERY SERVICES

A product that seeks to take advantage of emerging trends in the food sector is the Meal Kit Delivery service. While the first mainstream service emerged in 2007 (Review Chatter, 2017), the concept saw widespread adoption in the US beginning in 2015. Meal Kit Delivery (MK) services deliver pre-portioned ingredients for particular recipes (selected by the company) to residential households, where customers use directions to prepare a home cooked meal using the ingredients. Menus tend to be standardized across the country. In some cases, customers can choose their meals from a selection of up to eight meat and vegetarian options, while in others the meal options are fixed. Different services cater to different customer preferences, but overall most the companies seek to provide a gourmet eating experience with minimal shopping effort by the customer. MK services handle the hard work of selecting a recipe, sourcing all the ingredients needed to make it, and portioning ingredients into the right size needed for the particular meal. Customers are only responsible for the ultimate preparation of the meal. Thus, MK services claim to expand your culinary experiences while simultaneously reducing the amount of effort needed to prepare a meal at home.

At their price point ($20-25 for a 2-serving meal), MK services cater to upper income households with minimal free time but an overall affinity for home cooking and fresh foods. While the market remains niche at this point, its rapid growth suggests a broader expansion of these types of services may be on the horizon. The MK market reached $1 billion in sales in 2015, and is projected to grow 10-fold over the next decade (Technomic, 2016). One factor that may inhibit growth is the cost of MK services. While several studies have compared the cost of buying the ingredients for a MK meal from the grocery store and found some companies to be comparable, this does not consider that people typical prepare less complicated meals with more common ingredients when cooking at home. The USDA's food plan estimates the cost of all food purchased for preparation in the home ranges from $6.50 to $12.50 per person (for the thrifty and liberal plans, respectively) (USDA, 2014). A company named Handpicked seeks to capture the lower income market by partnering with grocery retailers to offer meal-kits that use lower cost items already available in the grocery store, thus maintaining the convenience factor of a MK service while keeping costs as low as $5.50 per person per meal (Carlos, 2015).

Besides the promise of expanding the culinary horizons of its customers, MK services also claim to play a role in reducing food waste (Peters, 2016). By portioning ingredients specifically to the size needed for an individual meal, less food ends up spoiled or thrown away as plate waste. Even if the overall rate of food waste at the customer level does not decrease, the total volume wasted could still be less since less food enters the household to begin with. This reduction in food waste at the customer level is only beneficial if it does not push the waste to other parts of the supply chain. Some MK companies also claim additional food waste reduction benefits at the warehouse and in distribution. For example, demand forecasting can be more accurate under a subscription model as precise customer needs are known at least several days in advance. In addition, by offering a smaller product mix companies can stock only the food they know is needed for a particular week's recipes. The elimination of the retail environment can also reduce food waste that occurs when produce spoils while sitting in the unrefrigerated environment of the grocery store. This reduction may come at a cost, however. Individually mailing packaged ingredients to households likely results in an increase in packaging waste. While several studies have shown that e-ordering generally uses less resources than the retail environment overall, the specific packaging requirements of food—and specifically produce and meats—is unique to this industry (Weideli, n.d.). For example, every box shipped must include icepacks and insulating material to avoid spoilage during shipment. Overall, increasing packaging requirements to reduce food waste remains a concern amongst MK service companies. In over a dozen articles on the growing MK service sector, almost all mention customer concern about packaging waste as a challenge that needs addressing (Erway, 2016).

A comparative analysis of the energy use and emission differences between each supply chain model—one based on subscription to a meal kit service and one based on traditional retail grocery environments—is necessary to fully understand the benefits and drawbacks of the MK model. Table 2 includes an assessment of the potential differences between MK services and the traditional grocery store supply chains, from farm to customer. In general, the very upstream portion of the supply chain is assumed to be the same. For example, there is no conclusive evidence that farming practices between meal kit suppliers and grocery store suppliers are significantly different. While there are variations between individual items sold at a grocery store and items included in a MK, it is assumed that uniquely sourced items (i.e. local, non-GMO, or organic) are available at the retail level as well. The source of ingredients is also assumed to be similar.

Traditional Grocery		Meal Kit Service
Primary energy and emissions in traditional grocery	**Impact Area**	**Potential differences in primary energy and emissions vs. traditional grocery**
Food waste	Farm	Assumed to be the same in this model. However, different demand planning capabilities may lead to less farm-level food waste if farmers can better plan for customer needs. In addition, if MK Services source directly from farmers there may be a reduction in resource use at the wholesale level.
Fertilizer and pesticide use		
Transportation to Processing		
Food waste in warehouse	Processing	
Energy use for warehouse		
Transportation to Wholesaler		
Food waste in warehouse	Wholesale	
Energy use for warehouse		
Transportation to Regional DC		
Energy use in warehouse	Regional Distribution Center	Energy use for refrigerated warehouse.
Food waste in warehouse		Increased food waste associated with kit preparation; Less food waste because of better demand planning
Transportation to Retail		No transportation to retail required (however transportation to mail carriers local distribution center is still required)
Energy use in retail store	Retail	No retail level food waste or energy use for buildings.
Food waste in retail store		Potential increase in energy use due to serves and computers used for online ordering.
Individual grocery trips in single household vehicles	Last Mile Transportation	Optimized delivery route reduces transportation emissions.
Food waste	Home	Less food waste due to controlled portions and precise ingredient volumes
Packaging Waste		Increased packaging for individual items and shipping materials

Table 2: Potential differences in primary energy and emissions in the MK Service supply chain compared to the traditional retail grocery store model. Not all potential differences are evaluated in this study due to data limitations.

While some Meal Kit Services claim to use locally sourced food (Blue Apron, n.d.), not enough data is available to determine what portion of their supply is locally sourced or what they define as local. For example, since MK Service weekly menus tend to be standardized nationwide, it is unlikely that every ingredient in every meal is grown throughout the country.

Differences in the supply chain begin to emerge once food reaches the regional distribution center. The traditional retail model requires energy use and transportation to retail grocery stores, and results in food waste throughout the process due to spoilage and damage. Under the meal kit model, energy use at the distribution center may be higher due to the use of fully refrigerated warehouses and extended time spent in the facility due to kit assembly. There may also be an increase in food waste associated with meal kit assembly (i.e. when dividing vegetables, etc.). However, food waste may also decrease due to better demand planning and reduced product offerings. Knowing the amount of food needed to fulfill orders for a particular week means MK services can make more informed ordering decisions, and purchase only the food needed for the known subscriptions. Alternatively, grocery stores use their own demand planning techniques to determine food ordering volume based on historic sales data analyzed for temporal, geographical, and seasonal fluctuations. Their inventory is still subjected to unexpected demand changes, however, which leads to food waste throughout the supply chain. A significant difference between the two models is the absence of retail energy use for buildings and retail food waste, which are not needed under the MK service supply chain model.

At the customer level, food waste and packaging waste will vary under the MK service model. Packaging waste is likely to increase as a result of smaller portion packaging and shipping materials, while food waste could decrease due to optimized ingredient volumes. From a transportation perspective, 'last mile' transportation also has differences under the two models. MK Service meals are delivered directly to households via optimized delivery routes, which could result in a decrease in energy use and emissions compared to driving individual cars to a grocery store. The total transportation distance and modes from the wholesale level to the start of the 'last mile' transit is likely similar, but may be slightly more efficient under MK service models if there are less wholesalers involved in the supply chain.

This comparison shows that there are a range of factors that could both increase and decrease energy and emissions under the MK service model. More detailed analysis of each is required to draw conclusions about the relative benefit of MK services over traditional grocery from environmental and economic perspectives.

REPORT STRUCTURE

The remainder of this report establishes a framework for analyzing primary energy use and carbon emissions for a typical MK service meal compared to a grocery-equivalent purchasing approach, and uses this information to estimate differences in energy and emissions costs between the two models. The Methodology section describes the process used to estimate energy use and carbon emissions under each scenario, including what factors are and are not considered as part of the analysis. The Analysis section describes the key conclusions and discusses primary drivers for each. Finally, the Implications sections recommends actions for key stakeholders based on this work.

Methodology

This study uses a combination of meta-analysis, direct measurement, and probabilistic analysis to estimate the relative primary energy use and emissions for MK services compared to an equivalent meal prepared using ingredients purchased from a traditional grocery store outlet. The approach used to capture relative energy use and emissions is based on a combination of data availability and established analysis methods. The differences between these scenarios is used to estimate potential economic savings based on energy and emission costs.

Scenarios Evaluated

This study focus on two scenarios:

1) MK Scenario: A 2- serving meal provided by a MK Service.
2) Grocery Scenario: The same 2-serving meal as Scenario 1 but prepared using supplies from a traditional grocery store outlet.

The ingredients in each meal are assumed to be the same, however in realty a range of different alternatives may be used in lieu of a MK service meal. Going to a restaurant or a fast food establishment, or preparing a completely different meal with ingredients purchased from the grocery store are all possible alternatives. Data limitations and challenges in developing comparable scenarios prevented a full analysis of MK service alternatives in this study. As more data becomes available and research on this topic continues, many of the frameworks applied in this study can be used to evaluate different combinations of MK service alternatives.

The inputs and externalities evaluated in this study are primary energy use and emissions. These data points were selected because of data availability and strong correlation with overall environmental benefits. For example, energy use is the leading source of greenhouse gas emissions worldwide (EPA, n.d.). Other environmental factors like water, land, and fertilizer use are important components of assessing environmental impact but are not analyzed in this study due to data limitations.

STUDY BOUNDARY

Figures 1 and 2 show simplified supply chains for the Grocery scenario and MK scenario, respectively. Blue shapes represent processes assumed to different between the two scenarios. Grey shapes are assumed to be the same across the scenarios but may still impact total energy and emissions due to food and packaging waste differences. The asterisk in Figure 1 represents the regional carrier distribution center; energy and emissions are not evaluated for this building because they are assumed to be small on a per package basis and reliable data is unavailable. The system boundary for the Grocery scenario begins at the retail grocery store. The MK service system boundary begins at the regional refrigerated warehouse (which is effectively used in lieu of a retail grocery environment), however transportation to the local mail carrier distribution center is excluded because total miles traveled to the local market is assumed to be the same under both scenarios. The specific factors evaluated are listed below. Subsequent sections in this chapter detail the specific methodology used for each factor.

- Building energy use
- Last mile transportation
- Product packaging
- Food waste
- End of life material management

Factors specifically excluded due to data limitations or assumed commonalities between the two scenarios are listed below. In some cases, difference in energy and emissions rates for a specific process are assumed to be the same, but the total energy use and emissions generated may be different depending on the volume of waste generated under each scenario.

- *Differences in energy use and emissions rates from the farm to wholesale.* There is no conclusive evidence that the MK service model would alter the rate of energy use and emissions in food preparation. While some MK services offer organic products, many customers also have access to the similar organic product offerings in their local grocery store.
- *All transportation energy and emission rates excluding 'last mile.'* The agriculture industry by nature is dependent on geography – farmers rely on weather patterns and soil health, among other factors, to produce particular food types. For example, 99% of the broccoli consumed in the US is grown in California. For this reason, the rate of energy use and emissions in the upstream portion of the supply chain is assumed to be the same for both models. While there may be benefits in the MK model if a majority of their products are locally sourced, there is not enough evidence to indicate this is practiced (as indicated by standard weekly menus used nationwide).
- *Impacts of different demand planning capabilities under a subscription based business model*. Demand planning for a subscription-based business will differ from a traditional retail model. However, there is not sufficient data available to accurately estimate the difference.
- *Other 'alternatives' to MK services (i.e. fast food, restaurants, etc.)* The energy use and emission profile for other MK service alternative will differ from the 'grocery-equivalent' scenario presented here. These alternatives are not considered due to data limitations and related challenges in developing a profile for a typical meal under these alternative scenarios.

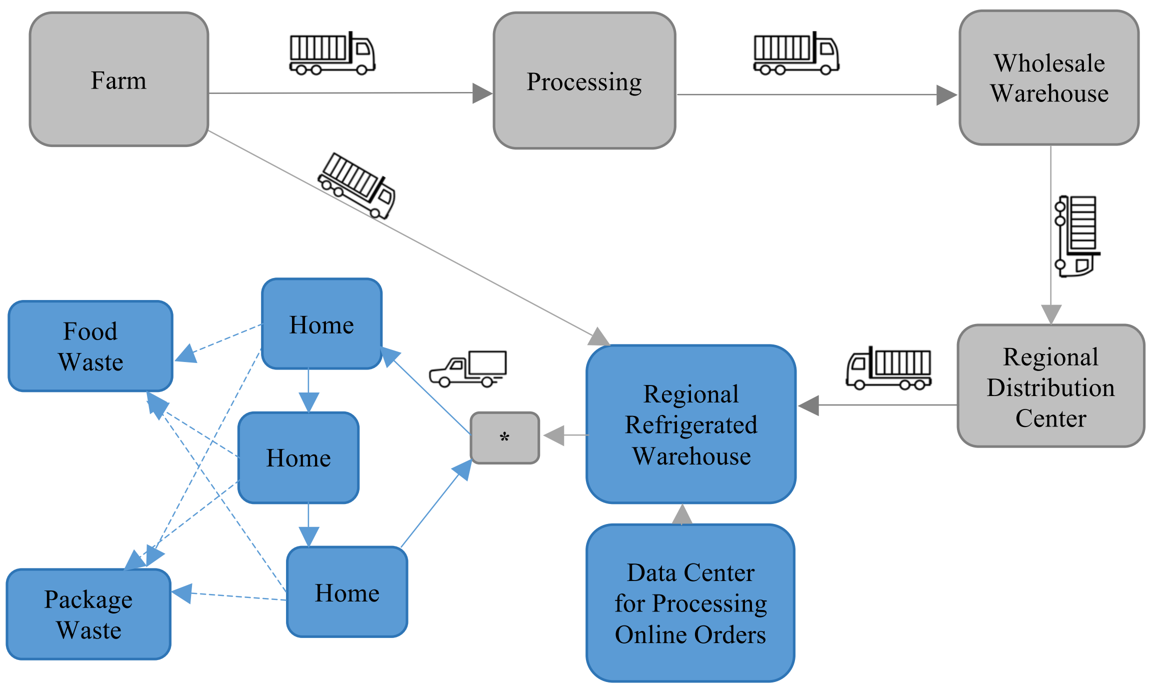

Figure 1: Simplified illustration of the supply chain for the MK scenario.

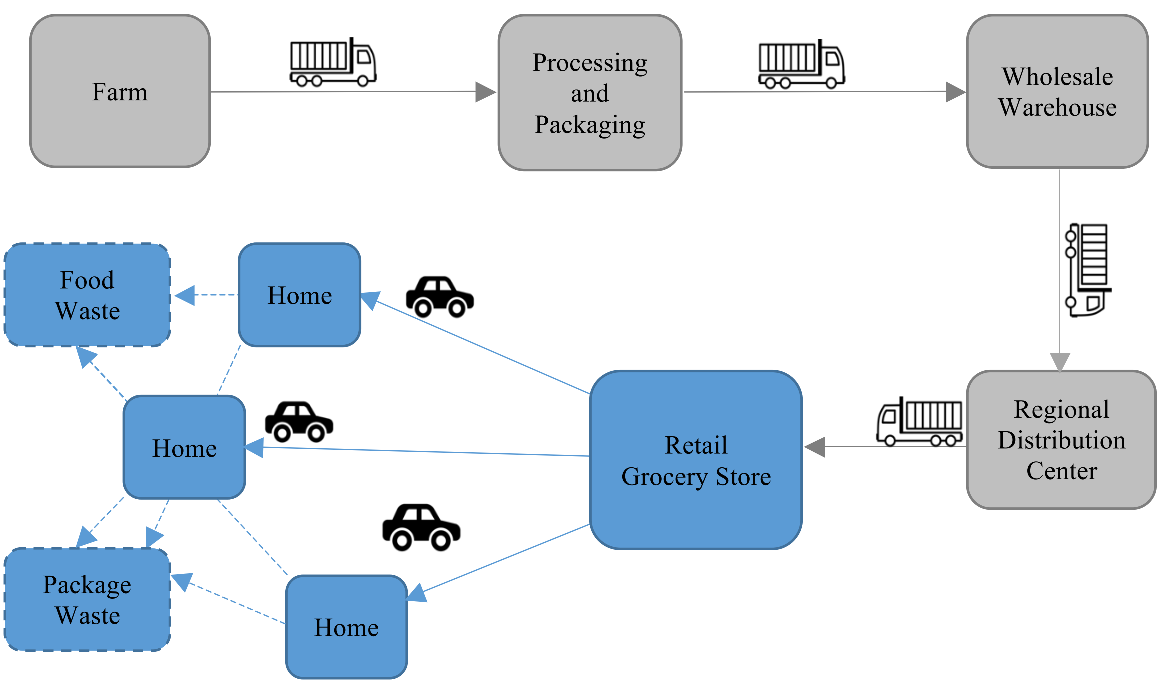

Figure 2: Simplified illustration of the supply chain for the Grocery scenario.

SUMMARY OF METHODS

A combination of direct measurement and meta-analysis is used to identify energy and emissions for each source under the two scenarios. A sample of 50 MK Service meals (for a total of 100 servings) from four different suppliers is used to identify product packaging and household food waste under the MK scenario. Details on the companies used and meal types are shown in Table 3, and a full list of the recipes evaluated is included in Appendix A. A sampling of companies is used to account for variations in food composition and packaging material type and weight across the industry. Companies were selected based on a combination of estimated market share and unique service offerings. For example, Plated allows for a selection of meals from a menu of 4 to 8 (depending on dietary restrictions). Blue Apron is estimated to be the largest distributor in the US, while Hello Fresh has an international presence. Green Chef offers the most variety of dietary restriction accommodation to customers (however, only two are evaluated under this study). While several other companies service customers across the US, these four are assumed to be representative of the broader industry.

Company	Total Meals	Vegetarian Meals	Carnivore Meals
Blue Apron	14	8	6
Hello Fresh	12	6	6
Green Chef	12	7	5
Plated	12	6	6
Total	**50**	27	23

Table 3: MK Meals by company and dietary type.

Packaging weight, total food volume, and food waste is manually measured and categorized for each MK service meal. The MK scenario meals also served as a basis for establishing a grocery-equivalent for customer packaging and food waste under the

Grocery scenario. For each item in each meal kit, a grocery store equivalent packaging weight per serving and total packaging size is determined based on products available at a regional grocery chain in Austin, TX. USDA household food waste averages by product are applied to the grocery store package size to determine a food waste volume under this scenario. Appendix B includes a description of product packaging definitions used in this study. Emissions and energy conversion factors are then applied to each product's packaging and food waste by category under each scenario. Total energy and emissions to produce consumed food are excluded. The remaining stages of the supply chain draw from a variety of data sources to determine an estimated range and/or average for energy use and emissions under each scenario.

Publicly available data with clear research methods is prioritized. In some cases, public data without documented research methods is used. Uncertainty is modeled for some values using probabilistic analysis via a Monte Carlo simulation with triangular distributions. All Monte Carlo simulations in this analysis use 10,000 iterations. The most likely value is estimated based on existing data, and minimum and maximum likely values are estimated or taken as the largest and smallest available data point. The methodology used to identify each data point is discussed in the sections below. Data tables are included in Appendix C.

ENERGY CONVERSION FACTORS

Energy conversion factors were developed for food production and distribution, packaging material production and distribution, building energy use, last mile transportation, and end of life material management. All conversion factors in this study are presented as kBtu per unit and are shown in Appendix C.

Food

The energy required to produce food is based on research by Cuellar and Webber for 14 food categories (Cuellar & Webber, 2010). The 'Food Handling' phase of energy use described by Cuellar and Webber is removed as these factors are captured independently based on differences in food handling for each scenario. The final energy values excluding food handling are scaled to 2010 using USDA Primary Food Weight changes and total energy use changes between 2004 and 2010, and then converted to kBtu/ounce. Table 12 in Appendix C includes a full accounting of energy conversion rates by food category.

Packaging

The energy required to produce packaging materials is primarily derived from the EPA Waste Reduction Model (WARM) documentation (EPA, 2015). 13 material types are used to reflect the typical composition of customer packaging materials. Values are converted from Million BTU/Short Ton to kBtu/Ounce. For each material, energy conversion factors were identified for 100% virgin and 100% recycled materials. The virgin factors are based on the 'Source Reduction' scenario and the recycled factors are based on the 'Recycled' scenario in WARM. A weighted average conversion factor is then used for each material to identify an energy use rate based on the recycled content of the item. The energy conversion factors used in this study do not include the embedded energy in materials that are petroleum-based (for example, plastics), and for that reason may vary slightly energy conversion rates used in the actual WARM calculator.

Two packaging materials are not included in EPA's WARM, and thus alternative estimates were developed. Ice pack filling is a material used in every MK service studied. The filling is typically composed of 99% water and 1% polyacrylate (C. F., Green Chef, personal communication, November 10, 2016). An estimate of the energy used to produce these materials is derived from two different Life Cycle Analysis studies – one for municipal water supply (Dettore, 2009) and one for polyacrylate (Gonita, 2014). The energy values are then weighted to develop an estimate of energy needed to create ice pack filling. The actual energy use is likely higher due to the processing of the two materials into the ice pack liner, however no specific data could be found to support this.

Another material used in approximately 50% of MK Service boxes is jute. Jute is a vegetable fiber that can be spun into threads. The material is woven into a 1 or 2-inch blanket, and is then wrapped around ingredients and icepacks to help serve as an insulator. Jute is not covered in EPA's WARM, nor are any other textile based materials that could serve as a substitute. No energy or emissions data could be located for this material. In general, jute has similar features to other fiber-based materials like bamboo and hemp. Life Cycle Analysis studies show that bamboo flooring products tend to be carbon neutral (van der Lugt & Vogtlander, 2015). This is because farming requires very little water and labor and no pesticides, and the plant is extremely fast growing. Given this, the jute material is assumed to have no energy or emission impacts. While this is not likely – as some energy is likely necessary produce the woven material—it is assumed to be a reasonable assumption based on currently available data.

The energy required to produce and distribute all virgin and recycled packaging materials found in this study is shown in Table 13 in Appendix C.

Buildings

Data compiled by Energy Star and based primarily on the Energy Information Administration (EIA) Commercial Building Survey is used to capture portions of the supply chain that involve energy use in buildings (Energy Star, n.d.). The Energy Star Portfolio manager includes average annual energy use per square foot for several building types by location, including refrigerated warehouses, grocery stores, and data centers. Annual energy use per square foot is identified for 15 geographic locations based on typical locations of distribution centers in the US (Steele, 2009). Distribution center locations are assumed to be in reasonable proximity to the markets they serve, and thus the same geographies are used to estimate grocery store energy use per square foot. The min, max, and median energy use per square foot by building type in these 15 locations served as the min, max, and most likely energy use per square foot and modeled via monte carlo simulation using a triangular distribution. The average value is then applied by building type and size as described in later sections of this chapter. The same process is used for the eight likely locations for data centers in the US (Latimer, 2011). Table 17 in Appendix C includes the min, max, and most likely values for annual data center energy use per square foot based on this analysis.

Last Mile Transportation

Transportation energy for food and packaging up until the retail level for the grocery store scenario and local carrier distribution center for the MK Service scenario is embedded in the energy conversion factors for packaging materials and food categories. As discussed earlier in this chapter, the transportation between upstream facilities—the farm and the local retail center or mail carrier distribution center—is considered to be roughly the same for the purpose of this model. Actual miles traveled for products may vary based on seasonality, ingredient mix, number of distribution centers, and a multitude of other factors that are difficult to quantify precisely without access to detailed supply chain information for the MK service industry, which is not currently available publicly. For 'last mile' transportation—the energy required to move products from the retail environment to the home— the energy content of petroleum fuels is sourced from the EPA as shown in Table 18 of Appendix C (EPA, 2014).

End of Life Management

The energy required for the end of life management of food and packaging materials is calculated separately based on the EPA WARM documentation (EPA, 2015). These values are converted from million Btu/short ton to kBtu/ounce. Each packaging material has an energy conversion rate, while all food is consolidated into one data point (i.e. there are not different end of life management energy conversion rates for different food types). For most materials energy use is predominately associated with transportation to the landfill, recycling or incineration facility, while emissions come from a range of sources at each site type. WARM's recycling conversion factors capture the energy used to produce a new item with recycled material. Since these energy and emissions are captured in the 'product packaging' phase of this model they are excluded from the end of life management conversion factors. End of life material management energy conversion factors by product type and material management method shown in Table 15 in Appendix C.

CARBON EMISSION CONVERSION FACTOR

Carbon emission conversion factors are developed for food production and distribution, packaging material production and distribution, building energy use, last mile transportation, and end of life material management. Carbon emissions are represented as pounds (lb.) of Carbon Dioxide equivalent (CO_2e) per unit. Thus, carbon emissions from non-CO_2 sources are translated into a CO_2 equivalent value based on their Global Warming Potential (GWP) over 100 years.

Food

The emissions from producing food are based on research by Heller and Keoleian. Values are organized into 13 food categories and converted from kg of CO_2e/kg to lb. of CO_2e/ounce for this study (Heller & Keoleian, 2015). Heller and Koeleians study does not include carbon emissions associated with transportation from the farm to the retail environment, however EPA's WARM includes estimates for carbon emissions associated with transportation of food products (EPA, 2015). Thus, Heller and Keoleian's production emission rates are combined with the EPA's transportation emission rates to arrive at a total emission rate per food category. The final carbon emission conversion factors for food are shown in Table 12 in Appendix C.

Packaging

The emissions generated from producing and transportation packaging materials is primarily derived from the EPA WARM documentation (EPA, 2015). 13 material types are used to reflect the typical composition of customer packaging materials. Values are converted from metric tons of CO_2e/short ton to lb. of CO_2e/ounce. For each material, emission factors were identified for 100% virgin and 100% recycled materials. The virgin factors are based on the 'Source Reduction' scenario and the recycled factors are based on the 'Recycled' scenario in WARM. A weighted average conversion factor is then used for each material to identify an emission rate based on the estimated recycled content of the item.

A majority of the virgin and recycled energy and emission conversion rates are not modeled as ranges, but their effective rate is variable based on the recycling material mix. The one exception to this is paper products. WARM considers both energy-related emissions and non-energy process emissions in calculating the total impact of source reduction and material recycling. For paper products, WARM considers the change in forest carbon storage potential as a result of harvesting timber to make paper. For virgin products, carbon sequestration loss makes up around 80% of the total emissions generated per ounce of product, significantly increasing the impact of their use. Whether the production of paper materials specifically used in either scenario will directly lead to avoiding deforestation is uncertain. This study accounts for this uncertainty by modeling a range of values for the carbon emission rate for virgin paper products. The min and max are based on carbon emissions without and with deforestation impacts, respectively. The most likely is the median between the two. These ranges are shown in Table 14 in Appendix C.

Two packaging materials are not included in the EPA WARM, and thus alternative estimates were developed. First, ice pack filling is a common material use by MK services. The filling is typically composed of 99% water and 1% polyacrylate (C. F., Green Chef, personal communication, November 10, 2016). The emissions from producing these materials are derived from two different life cycle analysis Studies – one for municipal water supply (Dettore, 2009) and one for polyacrylate (Gonita, 2014). The values are then weighted to come up with an estimate of emissions from creating ice pack filling. The actual emissions are likely higher due to the processing of the two materials into the ice pack liner, however no specific data could be found to support this.

Another material used in approximately 50% of MK Service boxes is jute. Jute is a vegetable fiber that can be spun into threads. The material is woven into a 1 or 2-inch blanket, and is then wrapped around ingredients and icepacks to help serve as an insulator. Jute is not included in EPA's WARM, nor are other textile based materials that could serve as a substitute. No energy or emissions data could be located for this material. In general, jute has similar features to other fast-growing fiber-based materials like bamboo and hemp. Life Cycle Analysis studies show that bamboo flooring products tend to be carbon neutral (van der Lugt & Vogtlander, 2015). This is because growing bamboo requires very little water, labor or pesticides, and is extremely fast growing. Given this, jute is assumed to have no emissions impacts in this model.

The emission rates associated with the production and distribution of all virgin and recycled packaging materials are shown in Table 13 in Appendix C.

Buildings

Data compiled by Energy Star and based primarily on the EIA Commercial Building Survey is used to capture portions of the supply chain that involve carbon emission from buildings. The Energy Star Portfolio manager includes total emissions for several building types by location, including refrigerated warehouses, grocery stores, and data centers (Energy Star, n.d.). Total building emissions are identified for 15 geographic locations based on typical locations of distribution centers in the US (Steele, 2009). Distribution center locations are assumed to be in reasonable proximity to the markets they serve, and thus the same geographies are used to estimate total grocery store emissions. Total emissions are divided by total building size to arrive at an annual emission rate per square foot. The min, max, and median emissions per square foot by building type in these 15 locations served as the min, max, and most likely emissions per square foot when modeled via monte carlo simulation using a triangular distribution. The average value is then applied by building type and size as described in later sections of this chapter. The same process is used for the eight likely locations for data centers in the US (Latimer, 2011). Table 17 in Appendix C includes the min, max, and most likely values for data center emissions per square foot based on this analysis.

Last Mile Transportation

Transportation emissions for food and packaging up until the retail level for the grocery store scenario and local carrier distribution center for the MK service scenario is embedded in the emissions conversion factors for packaging materials and food categories. As discussed earlier in this chapter, the transportation between upstream facilities—the farm and the local retail center or mail carrier distribution center—is assumed to be roughly the same for the purpose of this model. Actual miles traveled for products may vary based on seasonality, ingredient mix, number of distribution centers, and a multitude of other factors that are difficult to quantify precisely without access to details supply chain information for the MK service industry, which is not currently available publicly. For 'last mile' transportation—the movement of products from the retail environment to the home— emission rates are based on EPA data and applied based on fuel type (gasoline vs. diesel) as shown in Table 19 in Appendix C (EPA, 2014).

End of Life Material Management

The emissions generated through the end of life management of food and packaging materials is calculated separately based on the EPA's WARM documentation (EPA, 2015). These values are converted from million Btu/short ton to kBtu/ounce. Each packaging material has an emission conversion rate, while all food is consolidated into one data point (i.e. there are not different end of life management energy conversion rates for different food types). WARM's recycling conversion factors capture the emissions generated when producing a new item with recycled material. Since these energy and emissions are captured in the 'product packaging' phase of this model they are excluded from the end of life management conversion factors. End of life management emission conversion factors by material type and material management method are captured in Table 16 in Appendix C.

TOTAL ENERGY AND EMISSIONS

The total energy and emissions for each scenario is calculated using the formulas below. Abbreviations are defined in Table 4 and are used in formulas throughout this section. The remainder of this section details the specific methodology used for each component of total energy and total emissions under both scenarios. The results of this analysis are discussed in detail in the Findings chapter.

Grocery Scenario:

$$Total\ Energy\ (kBtu) = EGR_{BLDG} + EGR_{LMT} + EGR_{PP} + EGR_{FW} + EGR_{ELM}$$

$$Total\ Emissions\ (lb. CO^2e) = MGR_{BLDG} + MGR_{LMT} + MGR_{PP} + MGR_{FW} + MGR_{ELM}$$

Meal Kit Scenario:

$$Total\ Energy\ (kBtu) = EMK_{BLDG} + EMK_{LMT} + EMK_{PP} + EMK_{FW} + EMK_{ELM}$$

$$Total\ Emissions\ (lb. CO^2e) = MMK_{BLDG} + MMK_{LMT} + MMK_{PP} + MMK_{FW} + MMK_{ELM}$$

Abbreviation	Definition	Abbreviation	Definition
EMK	Energy – Meal Kit	BLDG	Building
MMK	Emissions – Meal Kit	LMT	Last mile transportation
EGR	Energy - Grocery	PP	Product packaging
MGR	Emissions – Grocery	FW	Food waste
		ELM	End of life material management

Table 4: Formula abbreviations for methodology section.

BUILDING: ENERGY AND EMISSIONS

As shown in Figures 1 and 2, a MK item and a grocery store food item take slightly different paths on their way to a customer's home. The upstream supply chain may be different than the traditional grocery item for some products—like produce—that MK services claim to source directly from farmers that process on site. Other processed goods likely follow a traditional supply chain path from the raw ingredients on the farm to packaged goods in a regional distribution center. As discussed earlier in this section, because the precise portion of food that is sourced directly from farmers in MK Service industry as a whole is unclear, the upstream portion of the supply chain is assumed to be the same and thus building energy use rates from the farm to the regional distribution center are not evaluated individually in this study.

Building energy use begins to vary once products leave a regional distribution center. Under the Grocery scenario, products travel to a local retail grocery store where customers purchase the items. Under the MK scenario, products travel to a regional refrigerated warehouse where the items are packaged, assembled into kits, and then shipped to the customer. Most MK service companies operate up to three regional refrigerated warehouses servicing US customers in the west, central, and eastern regions of the country. Once a MK service package leaves the refrigerated warehouse, it travels to a local mail carrier distribution center before being loaded on trucks for local delivery. Energy use at this building is assumed to be negligible and on a per package basis and thus excluded from the model. In addition, because MK Services are processed on the internet, data center capacity is needed to process and fulfill customer orders.

The specific methodology used to identify building energy use and emission under each scenario is described in detail below.

Grocery Scenario

For the Grocery scenario building energy use and emissions are measured for the retail grocery store. Determining energy use and emissions on a per meal basis requires identifying the total energy used and applying it to the products used in the meal based on cost. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using Monte Carlo simulation.

Energy

$$NGR_{BDG} = Energy\ Use\ per\ Sales\ \$ \times Cost\ per\ Meal$$

$$Energy\ Use\ per\ Sales\ \$ = \frac{(Building\ Square\ Feet \times Energy\ Factor\ )}{(Sales\ per\ Square\ Foot \times Building\ Square\ Feet)}$$

Emissions

$$EGR_{BDG} = Emissions\ per\ Sales\ \$ \times Cost\ per\ Meal$$

$$Emissions\ per\ Sales\ \$ = \frac{(Building\ Square\ Feet \times Emission\ Factor\ )}{(Sales\ per\ Square\ Foot \times Building\ Square\ Feet)}$$

- *Energy (kBtu/ft^2) and Emission Factors (lb. CO_2e/ft^2)* – The energy and emissions factors are as described in the ‘Energy Conversion Factors’ and ‘Emission Conversion Factors’ sections.
- *Building Square Feet (ft^2)* – The 2012 EIA Commercial Building Energy Consumption Survey is used to identify the range of grocery store sizes in the US (EIA, 2012). The min, max, and median square footage for the ‘Grocery/Supermarket’ building category in the survey are used to develop the min, max, and most likely square footage for a retail grocery store (as shown in Table 20 in Appendix C) and then modeled via Monte Carlo simulation using a triangular distribution.
- *Sales per Square Foot (\$/ft^2)* – Assumed to be \$11.03 based on the Food Marketing Institute’s data for 2015 (FMI, n.d.).

- *Cost per meal ($/meal)* – The range of equivalent cost of MK Service ingredients if purchased from a grocery store is based on cost difference estimates per serving for Hello Fresh, Blue Apron, and Green Chef services by Yates (Yates, 2016). The estimated differences for each service are subtracted from advertised per-serving rates, and multiplied by two to account for a 2-serving meal. The min, max and average are used as the min, max, and most likely value for cost per meal (as shown in Table 21 in Appendix C) and modeled via Monte Carlo Simulation using a triangular distribution.

Meal Kit Scenario

Determining energy use and emissions on a per meal basis requires identifying the total energy used and emissions generated and the total number of meals processed through each of the two facilities included–refrigerated warehouse and data center. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using Monte Carlo simulation.

Energy

$$NMK_{BLDG} = Regrigerated\ Warehouse\ Energy + Data\ Center\ Energy$$

$$Refirgerated\ Warehouse\ Energy = \frac{Building\ Square\ Feet \times Energy\ Factor}{Meals\ Processed\ per\ Facility}$$

$$Data\ Center\ Energy = \frac{Building\ Square\ Feet \times Energy\ Factor}{Meals\ Processed\ per\ Facility}$$

Emissions

$$MMK_{BLDG} = Regrigerated\ Warehouse\ Emissions + Data\ Center\ Emissions$$

$$Refirgerated\ Warehouse\ Emissions = \frac{Building\ Square\ Feet \times Emission\ Factor}{Meals\ Processed\ per\ Facility}$$

$$Data\ Center\ Emissions = \frac{Building\ Square\ Feet \times Emission\ Factor}{Meals\ Processed\ per\ Facility}$$

- *Energy (kBtu/ft^2) and Emission Factors (lb. CO_2e/ft^2)* – The energy and emission factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections.
- *Building Square feet (ft^2)* - The 2012 EIA Commercial Building Energy Efficiency Survey (EIA, 2012) is used to identify the range of refrigerated warehouse and data center sizes in the US. The min, max, and median square footage for the 'Refrigerated Warehouse' and 'Data Center' building categories in the survey are used to develop the min, max, and most likely square footage (as shown in Table 20 in Appendix B) and then modeled via Monte Carlo simulation using a triangular distribution.
- *Meals Processed (number of two serving meals)* – The number of meals processed is estimated based on public statements by meal kit companies regarding meals delivered in the United States. Blue Apron—the largest company in the US—claims to deliver 8 million servings[5] per month in the US (Griffith, 2016). Because this amount is not independently verifiable, a range of 25% above and below is calculated and used to simulate various processing quantities. It is assumed that meals are distributed evenly between three regional refrigerated warehouses serving the west, central, and east markets in the US, and that all online orders are processed through one data center. Table 22 in Appendix B shows the min, most likely, and max values for meals processed through each building type. These values are modeled via Monte Carlo simulation using a triangular distribution. A 0.7 correlation coefficient is used for Building Square Feet and Meals Processed to account for the direct relationship between the two variables (i.e. if more meals are processed more square feet would be required).

[5] Meal kit companies price based on an anticipated two servings per meal, and use the term meal to refer to each individual serving. A meal in this study refers to two servings of one recipe. Thus, Blue Apron statements were divided by two to account for the number of meals delivered as defined by this study.

Last Mile Transportation: Energy and Emissions

In the Grocery scenario, last mile transportation involves driving a passenger vehicle to the grocery store (other alternative modes of transportation like mass transit and walking are not included in this analysis). In the MK scenario, last mile transportation is the home delivery of the kit to individual households beginning at the local mail carrier distribution hub. The specific methodology used for each scenario is described below.

As discussed earlier in this chapter, the transportation between upstream facilities—the farm and the local retail center or mail carrier distribution center—is considered to be roughly the same for the purpose of this model. Actual miles traveled for products may vary based on seasonality, ingredient mix, number of distribution centers, and a multitude of other factors that are difficult to quantify precisely without access to detailed supply chain information for the MK Service industry, which is not currently available publicly.

Grocery Scenario

Energy and emissions for last mile transportation for the grocery store scenario is based on a combination of factors, including the distance from the home to a grocery store, vehicle miles per gallon (MPG), the number of weekly trips to the grocery store, and the number of meals purchased per trip. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using Monte Carlo simulation.

Energy:

$$NGR_{LMT} = \left(\left(\frac{RT\ Miles\ to\ Grocery\ Store}{Vehicle\ MPG}\right) \times Energy\ Factor\ per\ Gallon\right) \times \left(\frac{Weekly\ Trips}{Meal\ per\ Trip}\right)$$

Emissions:

$$MGR_{LMT} = \left(\left(\frac{RT\ Miles\ to\ Grocery\ Store}{Vehicle\ MPG}\right) \times Emission\ Factor\ per\ Gallon\right) + (RT\ Miles\ to\ Grocery\ Store * Emission\ Factor\ per\ Mile)) \times \left(\frac{Weekly\ Trips}{Meals\ per\ Trip}\right)$$

- *Energy (kBtu/gallon) and Emission Factors (lb. CO_2e/unit)* – The energy and emission factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections.
- *RT Miles to Grocery Store (miles/trip)* – The range of round trip miles to a grocery store or supermarket is based on research by Liu and Bing and published by the Center for Disease Control (CDC, 2015). Table 23 in Appendix C shows the min, most likely, and max values round trip miles to the grocery store. These values are modeled via Monte Carlo simulation using a triangular distribution.
- *Vehicle MPG (miles/gallon)* – Assumed to be 23.41, based on Department of Energy data on the average fuel economy for cars as of 2015 (EPA, 2015b).
- *Weekly Trips (trips)* – Based on data from the Food Marketing Institute (FMI, 2016). Table 23 in Appendix C shows the min, most likely, and max values for weekly grocery store trips. These values are modeled via Monte Carlo simulation using a triangular distribution.
- *Meals per week (meals)* – This refers to the number of meals purchased via trips to the grocery store in each week and is assumed to be 14. Although a typical person eats around 21 meals per week, this amount accounts for meals outside the home and consolidated purchasing for multiple meals (i.e. 1 quart of yogurt for a several days of breakfasts). This assumption is supported by research by Smith et al. that found between 65 and 72% of consumed food is supplied from the home (Smith, Ng, & Pompkin, 2013).

- Combined, the weekly trips and meals per trip values gives you the number of trips taken to the grocery store on a per meal basis.

Meal Kit Scenario

Energy and emissions for the MK Scenario are based on a combination of factors, including miles traveled per package and vehicle MPG. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using Monte Carlo simulation.

Energy:

$$NMK_{LMT} = \left(\left(\frac{Miles\ per\ Package}{Vehicle\ MPG}\right) \times Energy\ Factor\ per\ Gallon\right) \times Meals\ Per\ Package$$

Emissions:

$$MMK_{LMT} = \left(\left(\frac{Miles\ per\ Package}{Vehicle\ MPG}\right) \times Emission\ Factor\ per\ Gallon\right) + (Miles\ Per\ Package * Emission\ Factor\ per\ mile)) \times Meals\ Per\ Package$$

- *Energy (kBtu/gallon) and Emission Factors (lb. CO_2e/unit)* – The energy and emissions factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections.
- *Miles per package (miles)* – The range for miles traveled per package is based on four research studies comparing online shopping to retail shopping. Each of these studies uses a range of miles traveled per package for online shopping delivery based on several different delivery routing software packages, interviews with delivery drivers, and a variety of delivery scenarios (i.e. specific time, re-delivery required, etc). The min, max, and most likely miles traveled per package used in this model is based on a synthesis of these studies and is shown in Table 24 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution (Siikavirta, 2003)(Weber, 2008)((Weideli, n.d)(Ma, 2013).

- *Vehicle MPG (miles/gallon)* – Assumed to be 6.64, based on Department of Energy data on the average fuel economy for delivery trucks as of 2015 (EPA, 2015b).
- Meals per package (meals/package) – Assumed to be 3. Some MK Services allow for more meals per package, however in most cases 3 is the minimum and default subscription setting.

PRODUCT PACKAGING: ENERGY AND EMISSIONS

Product packaging includes the individual packaging used to protect a food item as it travels through the supply chain and is ultimately purchased by a customer, and the packaging used to deliver multiple purchased items to the household. In the Grocery scenario, packaging includes paper, plastic, and metal containers for processed food, plastic bags for fresh produce, and plastic bags for carrying products from the store to the home. In the Meal Kit scenario, product packaging includes the individually packaged items in each kit—which include paper, plastic, and metal containers— as well as the delivery packaging which includes corrugate, paper, plastic, ice packs, and jute insulation. The specific methodology used for each scenario is described below.

Grocery Scenario

The inventory of items used to determine total product packaging for the Grocery scenario is developed based on 50 meal kit menus from four companies (the same product mix used in the Meal Kit scenario). For each item, a grocery store-equivalent item is selected and its packaging material and weight identified through manual measurement. Grocery-store equivalent items were selected by balancing both the typical packaging size for that type of item and the amount required by the recipe. For example, if a recipe called for a small amount of an item, the most common sized items is selected over personal or bulk sized packaging. When no common package size could be identified, the size closest to what the recipe called for is used. Private label items were selected when available. Energy and emissions factors are then applied to the average modeled packaging weight by material. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using Monte Carlo simulation.

Energy:

$$NGR_{PP} = \sum(Weight\ of\ Packaging\ Type_X \times Energy\ Conversion\ Rate_x) + (Weight\ of\ Packaging\ Type_y \times Energy\ Conversion\ Rate_y) + \cdots (Weight\ of\ Packaging\ Type_z \times Energy\ Conversion\ Rate_z)$$

Emissions:

$$MGR_{PP} = \sum(Weight\ of\ Packaging\ Type_X \times Emission\ Conversion\ Rate_x) + (Weight\ of\ Packaging\ Type_y \times Emission\ Conversion\ Rate_y) + \cdots (Weight\ of\ Packaging\ Type_z \times Emission\ Conversion\ Rate_z)$$

- *Energy (kBtu/ounce) and Emission Factors (lb. CO_2e/ounce)* – The energy and emissions factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections. The actual virgin and recycled energy and emission conversion rates are not modeled as ranges, but the effective rate is variable based on the recycling material mix, which is modeled as a range. The recycled content of each material is modeled using a triangular distribution to determine the average energy conversion rate under multiple material composition scenarios. The min, max, and most likely recycling mix is based on EPA's WARM documentation, which includes the current minimum, current mix, and max recycled content for each product type, shown in Table 25 in Appendix C (EPA, 2015). These values are modeled via Monte Carlo simulation using a triangular distribution.
- *Weight of Packaging Type (ounces)* – The total packaging by material type is recorded for each of the 50 meal kit recipes. When multiple materials are used in one singular packaging item (i.e. glass jar with a plastic lid) the item is classified

according to the predominate material used. When a material is clearly plastic or paper but the exact material type is unclear, the item is recorded as mixed plastic or mixed paper (both are material paths available in WARM). Packaging that weighs under 1 gram is not counted. The total material weight is averaged over 50 meals to identify an average package weight by material type, as shown in Table 26 in Appendix C.

Meal Kit Scenario

The inventory of items used for the MK scenario is based on 50 MK Meals sourced from four MK service companies. Each item's individual packaging is categorized by material type and weighed. The shipping materials were also categorized and weighed and the weight distributed evenly amongst the three meals per shipment. Energy and emissions factors are then applied to the average packaging weight by material. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors are modeled using Monte Carlo simulation.

Energy:

$$NMK_{PP} = \sum(Weight\ of\ Packaging\ Type_X \times Energy\ Conversion\ Rate_x) + \left(Weight\ of\ Packaging\ Type_y \times Energy\ Conversion\ Rate_y\right) + \cdots (Weight\ of\ Packaging\ Type_z \times Energy\ Conversion\ Rate_z)$$

Emissions:

$$MMK_{PP} = \sum(Weight\ of\ Packaging\ Type_X \times Emission\ Conversion\ Rate_x) + \left(Weight\ of\ Packaging\ Type_y \times Emission\ Conversion\ Rate_y\right) + \cdots (Weight\ of\ Packaging\ Type_z \times Emission\ Conversion\ Rate_z)$$

- *Energy (kBtu/ounce) and Emission Factors (lb. CO_2e/ounce)* – The energy and emissions factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections. The actual virgin and recycled energy and emission conversion rates are not modeled as ranges, but the effective rate is variable based on the recycling material mix, which is modeled as a range. The recycled content of each material is modeled using a triangular distribution to determine the average energy conversion rate under multiple material composition scenarios. The min, max, and most likely recycling mix is based on EPA's WARM documentation, which includes the current minimum, current mix, and max recycled content for each product type, shown in Table 25 in Appendix C (WARM, 2015). These values are modeled via Monte Carlo simulation using a triangular distribution.

- *Weight of Packaging Type (ounces)* – The total packaging by material type is recorded for each of the 50 meal kit recipes. When multiple materials are used in one singular packaging item (i.e. glass jar with a plastic lid) the item is classified according to the predominate material used. When a material is clearly plastic or paper but the exact material type is unclear, the item is recorded as mixed plastic or mixed paper (both are material paths available in WARM). Packaging that weighs under 1 gram is not counted. The total material weight is averaged over 50 meals to identify an average package weight by material type, shown in Table 26 in Appendix C.

FOOD WASTE

Food waste is the edible food that is disposed of in the home due to spoilage or leftovers that remain uneaten. The Grocery Scenario uses a 'grocery-equivalent' packaging size for each item in the 50 MK recipes studied, and then applies average household inedible food waste by food category according to the USDA Loss Adjusted Food Availability research (USDA, 2010). The total food waste is then distributed based on the average number of meals that can be prepared with the package size. The MK scenario relies on direct measurement of total food weight and inedible food waste by food category for each of the 50 MK meals. Energy and emissions factors are then applied to the average wasted food weight by food category. The specific formulas for energy and emissions for each scenario are shown below.

Grocery Scenario

The inventory of items used to determine total product packaged for the Grocery scenario is developed based on 50 meal kit menus from four companies (the same product mix used in the Meal Kit Scenario). For each item, a grocery store-equivalent item is selected and its packaging size identified. Grocery-store equivalent items were selected by balancing both the typical packaging size for that type of item and the amount required by the recipe. For example, if a recipe called for a small amount of an item, the most common sized items is selected over personal or bulk sized packaging. When no common package size could be identified, the size closest to what the recipe called for is used. Private label items were selected when available. A waste rate is then applied to the average package weight by food category. Finally, the wasted food energy and emission is then divided by the meals per package size factor by food category to ensure wasted energy is accurately distributed over the number of meals that can be prepared using the packaged item. The specific formulas for energy and emissions are shown below. No variables are modeled using Monte Carlo Distribution for food waste in the grocery scenario.

Energy:

$$NGR_{FW} = Retail\ Food\ Waste\ Energy + Household\ Food\ Waste\ Energy$$

$$\begin{aligned} &Household\ Food\ Waste\ Energy \\ &\quad = \sum\left(\frac{(Weight\ of\ Food\ Type_X \times Household\ Waste\ Rate_x \times Energy\ Conversion\ Rate_x)}{Meals\ per\ Package\ Size_x}\right) \\ &\qquad + \left(\frac{(Weight\ of\ Food\ Type_y \times Household\ Waste\ Rate_y \times Energy\ Conversion\ Rate_y)}{Meals\ per\ Package\ Size_y}\right) \\ &\qquad + \cdots\left(\frac{(\ Weight\ of\ Food\ Type_z \times Household\ Waste\ Rate_z \times Energy\ Conversion\ Rate_z)}{Meals\ per\ Package\ Size_y}\right) \end{aligned}$$

$$Retail\ Food\ Waste\ Energy = \sum\left(\frac{(Weight\ of\ Food\ Type_x \times Energy\ Conversion\ Rate_x \times Retail\ Food\ Waste\ Rate_x)}{Meals\ per\ Package\ Size_x}\right) + \left(\frac{(Weight\ of\ Food\ Type_y \times Energy\ Conversion\ Rate_y \times Retail\ Food\ Waste\ Rate_y)}{Meals\ per\ Package\ Size_y}\right) \cdots + \left(\frac{(Weight\ of\ Food\ Type_z \times Energy\ Conversion\ Rate_z \times Retail\ Food\ Waste\ Rate_z)}{Meals\ per\ Package\ Size_z}\right)$$

Emissions:

$$MGR_{FW} = Retail\ Food\ Waste\ Emissions + Household\ Food\ Waste\ Emissions$$

$$Household\ Food\ Waste\ Emissions = \sum\left(\frac{(Weight\ of\ Food\ Type_X \times Household\ Waste\ Rate_x \times Emission\ Conversion\ Rate_x)}{Meals\ per\ Package\ Size_x}\right) + \left(\frac{(Weight\ of\ Food\ Type_y \times Household\ Waste\ Rate_y \times Emission\ Conversion\ Rate_y)}{Meals\ per\ Package\ Size_y}\right) + \cdots \left(\frac{(Weight\ of\ Food\ Type_z \times Household\ Waste\ Rate_z \times Emission\ Conversion\ Rate_z)}{Meals\ per\ Package\ Size_y}\right)$$

$$Retail\ Food\ Waste\ Emissions = \sum\left(\frac{(Weight\ of\ Food\ Type_x \times Emission\ Conversion\ Rate_x \times Retail\ Food\ Waste\ Rate_x)}{Meals\ per\ Package\ Size_x}\right) + \left(\frac{(Weight\ of\ Food\ Type_y \times Emission\ Conversion\ Rate_y \times Retail\ Food\ Waste\ Rate_y)}{Meals\ per\ Package\ Size_y}\right) \cdots + \left(\frac{(Weight\ of\ Food\ Type_z \times Emission\ Conversion\ Rate_z \times Retail\ Food\ Waste\ Rate_z)}{Meals\ per\ Package\ Size_z}\right)$$

- *Energy (kBtu/ounce) and Emission Factors (lb. CO_2e/ounce)* – The energy and emissions factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections.
- *Food Weight (ounces)* – The grocery-equivalent total packaged weight for each item in the 50 MK recipes is documented by 14 food categories for each meal. This data is used to develop an average food weight per meal by food category, as shown in Table 27 in Appendix C. The packaged food weight is used as the basis for both household and retail food loss. Retail food loss is assumed to have taken place based on the food category, but would not apply to the specific food items used in the meal (as they were purchased, and thus not wasted). However, because the customer chooses to buy

from this particular outlet the wasted food created by keeping the particular items stocked is attributed to the meal.

- *Food Waste Rate (%)* – Both the household and retail food waste rate for the grocery scenario ware based on the USDA Loss Adjusted Food Availability dataset (USDA, 2010). Waste rates by food category are shown in Table 28 in Appendix C.
- *Meals per Package Size (meals/package ounces)* – This factor is used to ensure food waste for the total package size purchased is distributed evenly over the number of meals it can being used. For each item, an estimated meal per package size is developed by diving the total package size by the food amount required in the recipe. To simplify the model, an average meal per package size is tabulated by food category. This average is weighted based on the food amount required by the recipe to ensure that large package size items (like loose sugar) did not skew the average. The final weighted average meals per package size by food category are shown in Table 29 in Appendix C.

Meal Kit Scenario

Food waste under the MK scenario is directly measured for each of the 50 MK service meals evaluated in this study and applied to the total food volume by category. The waste rates by meal are used to develop a range of food waste rates for each food category. Food waste rates in a meal kit refrigerated warehouse have not been publicly documented, so a range of values is estimated and modeled. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using Monte Carlo simulation.

Food waste can vary significantly across households, as time, disposable income, dietary restrictions, and pickiness play a role in each individual eating habit. This study relied on only two households, which is not a statistically significant amount for an extremely variable factor like household food waste. However, Blue Apron recently published the results of a survey of 2,000 customers to determine how their product impacts household food waste, and found that 7.6% of the food in Blue Apron meals is wasted (Peters, 2016). In comparison, the average inedible food waste measured across all food categories during this study is 7.8%. While the Blue Apron study is a useful benchmark, it did not include details about methodology or food waste by specific food categories. Thus, the observed household inedible food waste rates for the 50 MK meals in this study are used to establish the boundaries for a triangular distribution, and are considered reliable because the overall findings are consistent with Blue Apron's study of a much larger population size.

Energy:

$$NMK_{FW} = Warehouse\ Food\ Waste\ Energy + Household\ Food\ Waste\ Energy$$

$$\begin{aligned} &Household\ Food\ Waste\ Energy \\ &= \sum (Weight\ of\ Food\ Type_X \times Household\ Waste\ Rate_x \times Energy\ Conversion\ Rate_x) \\ &+ (Weight\ of\ Food\ Type_y \times Household\ Waste\ Rate_y \times Energy\ Conversion\ Rate_y) \\ &+ \cdots (Weight\ of\ Food\ Type_z \times Household\ Waste\ Rate_z \times Energy\ Conversion\ Rate_z) \end{aligned}$$

$$\begin{aligned} &Warehouse\ Food\ Waste\ Energy \\ &= \sum (Weight\ of\ Food\ Type_X \times Warehouse\ Waste\ Rate_x \times Energy\ Conversion\ Rate_x) \\ &+ (Weight\ of\ Food\ Type_y \times Warehouse\ Waste\ Rate_y \times Energy\ Conversion\ Rate_y) \\ &+ \cdots (Weight\ of\ Food\ Type_z \times Warehouse\ Waste\ Rate_z \times Energy\ Conversion\ Rate_z) \end{aligned}$$

Emissions:

$$MMK_{FW} = Retail\ Food\ Waste\ Emissions + Household\ Food\ Waste\ Emissions$$

$$\begin{aligned} &Household\ Food\ Waste\ Emissions \\ &= \sum (Weight\ of\ Food\ Type_X \times Household\ Waste\ Rate_x \times Emission\ Conversion\ Rate_x) \\ &+ (Weight\ of\ Food\ Type_y \times Household\ Waste\ Rate_y \times Emission\ Conversion\ Rate_y) \\ &+ \cdots (Weight\ of\ Food\ Type_z \times Household\ Waste\ Rate_z \times Emission\ Conversion\ Rate_z) \end{aligned}$$

$$
\begin{aligned}
&Warehouse\ Food\ Waste\ Emission \\
&\quad = \sum (Weight\ of\ Food\ Type_x \times Warehouse\ Waste\ Rate_x \times Emission\ Conversion\ Rate_x) \\
&\qquad + (Weight\ of\ Food\ Type_y \times Warehouse\ Waste\ Rate_y \times Emission\ Conversion\ Rate_y) \\
&\qquad + \cdots (Weight\ of\ Food\ Type_z \times Warehouse\ Waste\ Rate_z \times Emission\ Conversion\ Rate_z)
\end{aligned}
$$

- *Energy (kBtu/ounce) and Emission Factors (lb. CO_2e/ounce)* – The energy and emissions factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections.
- *Food Weight (ounces)* – The total packaged weight for each item in the 50 MK recipes is documented by 14 food categories. This data is used to develop an average food weight per meal by food category, as shown in Table 24 in Appendix C.
- *Household Food Waste Rate (%)* – The MK Scenario relies on direct measurement of inedible food waste by food category for each of the 50 MK meals. Non-spoiled leftovers are considered inedible if uneaten three days after the meal is prepared. The min, max, and median inedible food waste by food category over these 50 meals is the used to establish a min, max, and most likely ratio of food wasted for the triangular distribution, as shown in Table 30 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution.
- *Warehouse Food Waste Rate (%)* – Food waste in a meal kit refrigerated warehouse has not been publicly documented. Blue Apron released the results of a study of food waste in their warehouse over a 2-week period and found that the overall food waste rate is 5.5%. Although the methodology and rates by food category are not published, it remains the best estimate available for this specific food service establishment and is thus used as the most likely value in a triangular distribution for all food categories. To allow for variations in food waste rates, the United Nations Food Agriculture Organization estimates for processing and packaging food waste (or the Blue Apron estimate, whichever is greater) is used as the maximum. The min is then calculated so

that the 'Most Likely' value is the average of the min and max values. The distributions by food category are shown in Table 31 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution.

END OF LIFE MANAGEMENT: ENERGY AND EMISSIONS

Once a product is discarded—whether it be packaging or food—energy and emissions are associated with its ongoing management. The energy use and emissions per ounce of disposed items depends on both the material type and the particular disposal mechanism, which includes recycling, landfilling, and combustion with waste to energy for product packaging and landfilling and compositing for food. The EPA's WARM documentation is used to identify energy and emission factors for each material management option by material type (EPA, 2015). The volume of product requiring end of life management is based on the average total product packaging and food waste for each scenario (as described in the previous two sections). The combination of material management approaches is modeled using the EPA's current data on household waste disposal patterns as the most likely scenario (EPA, 2016). The specific formulas for energy and emissions for each scenario are shown below.

Grocery Scenario

The total volume of material requiring end of life management by material type is based on the total average weight by material and food item as describe the previous two sections – Food Waste and Product Packaging. The likely material management method is then determined by using a Monte Carlo Simulation for the two key factors influencing end of life energy and emissions – portion recycled and portion composted. The portion of materials destined for waste to energy facilities is based on EPA's annual MSW research study and assumed to remain constant as the capacity of these facilities has also remained constant in recent years (EPA, 2016). The portion of materials destined for the landfill is assumed to be the remaining material weight after taking into account the portion combusted and the modeled portion recycled or composted. Conversion factors for landfilling, composting, recycling, and incineration with energy recovery are applied based on the modeled material management use by method. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using Monte Carlo simulation.

Energy:

$$NG_{ELM} = End\ of\ Life\ Food\ Waste\ Energy + End\ of\ Life\ Product\ Packaging\ Energy$$

$$\begin{aligned} &End\ of\ Life\ Food\ Waste\ Energy \\ &= (Total\ Food\ Waste \times \%Composted \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Landfilled \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Combusted \times Energy\ Conversion\ Factor_x) \end{aligned}$$

$$\begin{aligned} &End\ of\ Life\ Packaging\ Energy \\ &= \sum ((Total\ Packaging_x \times \%Recycled_x \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Landfilled_x \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Combusted_x \times Energy\ Conversion\ Factor_x)) \ldots \\ &+ ((Total\ Packaging_y \times \%Recycled_y \times Energy\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Landfilled_y \times Energy\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Combusted_y \times Energy\ Conversion\ Factor_y)) \end{aligned}$$

Emissions:

$$MG_{ELM} = End\ of\ Life\ Food\ Waste\ Emission + End\ of\ Life\ Product\ Packaging\ Emission$$

$$\begin{aligned} &End\ of\ Life\ Food\ Waste\ Emission \\ &= (Total\ Food\ Waste \times \%Composted \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Landfilled \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Combusted \times Emission\ Conversion\ Factor_x) \end{aligned}$$

$$\begin{aligned} &End\ of\ Life\ Packaging\ Emission \\ &= \sum ((Total\ Packaging_x \times \%Recycled_x \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Landfilled_x \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Combusted_x \times Emission\ Conversion\ Factor_x)) \ldots \\ &+ ((Total\ Packaging_y \times \%Recycled_y \times Emission\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Landfilled_y \times Emission\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Combusted_y \times Emission\ Conversion\ Factor_y)) \end{aligned}$$

- *Energy (kBtu/ounce) and Emission (lb. CO_2e) Conversion Factors* – The energy and emissions factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections.
- *Total Packaging (ounces)* – The total packaging by product type is calculated as described in the 'Product Packaging' section of this chapter. In sum, an average packaging volume by material type is determined based on direct measurement of packaging waste for the 50 MK recipes evaluated in this study.
- *Total Food Waste (ounces)* – The total food waste is calculated as described in the 'Food Waste' section of this chapter. In sum, an average food waste volume is calculated by multiplying the average measured food waste volume over 50 MK Meals by average waste rates published by the USDA (USDA, 2010).
- *Portion Recycled (%)* – The portion of materials recycled is based on EPA estimates for current recycling rates by material and the min and max portion of the material that can conceivably be recycled. The current national average recycling rate is used as the most likely value (EPA, 2016). A 0% and 100% recycling rate is used for the minimum and maximum, respectively. The distribution ranges by material type are shown in Table 32 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution.
- *Portion Composted (%)* – The portion of waste food that is composted is based on EPA estimates for current composting rates for food products and the min and max portion of the material that can conceivably be recycled. The current national average composting rate is used as the most likely value (EPA, 2016). A 0% and 100% composting rate is used for the minimum and maximum, respectively. The distribution range is shown in Table 33 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution.

- *Portion Combusted (%)* – The portion of materials combusted is a static value based on EPA estimates of current combustion rates by material type (EPA, 2016). This value is not modeled as a range because the trend in combustion rates has remained stagnant for over a decade, largely due to environmental regulations related to combustion emissions and the high costs required to build new combustion plants. The portion combusted by material type is shown in Table 34 in Appendix C.
- *Portion Landfilled (%)* – The portion of materials landfilled is assumed based on a combination of the static portion combusted value by material and the modeled portion recycled (for packaging) or composted (for food waste). The remaining portion (out of 100%) is assumed to be landfilled. Thus: Portion Landfilled = 1.0 – Portion Recycled/Composted – Portion Combusted. The value itself is not modeled as a range, but is based on the modeled recycling/composting value and thus is variable.

Meal Kit Scenario

The total volume of material requiring end of life management by material type is based on the total average weight by material and food item as describe the previous two sections – Food Waste and Product Packaging. The likely material management method is then determined by using a triangular distribution for the two key factors influencing end of life energy and emissions – portion recycled and portion composted. The proportion of materials destined for waste to energy facilities is based on EPA's annual MSW research study and assumed to remain constant as the capacity of these facilities has not changed in recent years (EPA, 2016). The portion of materials destined for the landfill is assumed to be the remaining after taking into account the portion combusted and the modeled portion recycled or composted. Emission conversion factors for landfilling, composting, recycling, and incineration with energy recovery are applied based on the modeled material management use by method. The specific formulas for energy and emissions are shown below. Portions of the equation in red represent variable factors that are modeled using a triangular distribution.

Energy:

$$NMK_{ELM} = End\ of\ Life\ Food\ Waste\ Energy + End\ of\ Life\ Product\ Packaging\ Energy$$

$$\begin{aligned} End\ of\ Life\ Food\ Waste\ Energy &= (Total\ Food\ Waste \times \%Composted \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Landfilled \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Combusted \times Energy\ Conversion\ Factor_x) \end{aligned}$$

$$\begin{aligned} End\ of\ Life\ Packaging\ Energy &= \sum((Total\ Packaging_x \times \%Recycled_x \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Landfilled_x \times Energy\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Combusted_x \times Energy\ Conversion\ Factor_x)) \ldots \\ &+ ((Total\ Packaging_y \times \%Recycled_y \times Energy\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Landfilled_y \times Energy\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Combusted_y \times Energy\ Conversion\ Factor_y)) \end{aligned}$$

Emissions:

$$MMK_{ELM} = End\ of\ Life\ Food\ Waste\ Emission + End\ of\ Life\ Product\ Packaging\ Emission$$

$$\begin{aligned} End\ of\ Life\ Food\ Waste\ Emission &= (Total\ Food\ Waste \times \%Composted \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Landfilled \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Food\ Waste \times \%Combusted \times Emission\ Conversion\ Factor_x) \end{aligned}$$

$$\begin{aligned} End\ of\ Life\ Packaging\ Emission &= \sum((Total\ Packaging_x \times \%Recycled_x \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Landfilled_x \times Emission\ Conversion\ Factor_x) \\ &+ (Total\ Packaging_x \times \%Combusted_x \times Emission\ Conversion\ Factor_x)) \ldots \\ &+ ((Total\ Packaging_y \times \%Recycled_y \times Emission\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Landfilled_y \times Emission\ Conversion\ Factor_y) \\ &+ (Total\ Packaging_y \times \%Combusted_y \times Emission\ Conversion\ Factor_y)) \end{aligned}$$

- *Energy (kBtu/ounce) and Emission (lb. CO_2e) Conversion Factors* – The energy and emissions factors are as described in the 'Energy Conversion Factors' and 'Emission Conversion Factors' sections.

- *Total Packaging (ounces)* – The total packaging by product type is calculated as described in the ‘Product Packaging’ section of this chapter. In sum, an average packaging volume by material type is determined based on direct measurement of packaging waste for the 50 MK recipes evaluated in this study.
- *Total Food Waste (ounces)* – The total food waste by is calculated as described in the ‘Food Waste’ section of this chapter. In sum, a range of food waste rates are determined by measuring actual food waste over 50 MK Meals. The range and median of food waste by food category is then modeled using Monte Carlo distribution. The modeled waste rates are multiplied by the average food per meal by food category.
- *Portion Recycled (%)* – The portion of materials recycled is based on EPA estimates for current recycling rates by material and the min and max portion of the material that can conceivably be recycled. The current national average recycling rate is used as the most likely value (EPA, 2016). A 0% and 100% recycling rate is used for the minimum and maximum, respectively. The distribution ranges by material type are shown in Table 32 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution.
- *Portion Composted (%)* – The portion of waste food that is composted is based on EPA estimates for current composting rates for food products and the min and max portion of the material that can conceivably be recycled. The current national average composting rate is used as the most likely value (EPA, 2016). A 0% and 100% composting rate is used for the minimum and maximum, respectively. The distribution range is shown in Table 33 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution.

- *Portion Combusted (%)* – The portion of materials combusted is a static value based on EPA estimates of current combustion rates by material type (EPA, 2016). This value is not modeled as a range because the trend in combustion rates has remained stagnant for over a decade, largely due to environmental regulations related to combustion emissions and the high costs required to build new combustion plants. The portion combusted by material type is shown in Table 34 in Appendix C.
- *Portion Landfilled (%) – T*he portion of materials landfilled is assumed based on a combination of the static portion combusted value by material and the modeled portion recycled (for packaging) or composted (for food waste) for all materials except ice pack filling. The remaining portion (out of 100%) is assumed to be landfilled. Thus: Portion Landfilled = 1.0 – Portion Recycled/Composted – Portion Combusted. The value itself is not modeled as a range, but is based on the modeled recycling/composting value and thus is variable. The exception to this approach is ice pack filling. While ice pack filling is soluble and can be disposed of into backyards or the whole pack reused, it is expected that some users may choose to dispose of this in a landfill due to convenience. For this reason, the landfill rate is modeled using a distribution range of 0% and 100%, with 50% being the most likely value. The distribution range for ice pack filling landfill rates is shown in Table 35 in Appendix C. These values are modeled via Monte Carlo simulation using a triangular distribution.

ECONOMIC IMPACT

The economic impact of these scenarios can also be evaluated by both overall energy and emissions savings. While energy is priced in the U.S., carbon emissions are typically not priced. However, carbon tax policies are expanding worldwide suggesting that carbon pricing may impact MK service or Grocery operations in some markets in the future. The collective energy and emissions costs are used as a measure of economic impact of each scenario. It is important to note that if a carbon tax or cap and trade measure is implemented in the U.S. the cost of emissions related to energy production would likely be embedded in energy costs. Since there is not a widespread carbon tax policy in the U.S. currently, energy and emissions costs are calculated separately and summed. The following sections below describe the method used to develop these costs estimates.

Total Energy

Energy is one metric used to evaluate the impact of the MK scenario relative to a traditional Grocery scenario. Because there is a cost associated with energy use, this metric can be used to estimate the economic benefit of the lower energy use scenario. A range of energy types are used in this study– from gasoline, to electricity from different sources, and steam and heat for HVAC systems. In some phases of the supply chain, details about the particular fuel source for energy use are known while in others the precise breakdown is unclear because of data limitations. Thus, a combination of fuel specific energy costs and total energy costs from all sources is used to estimate energy costs for each scenario. The EIA estimates consumer energy costs per Btu by end use sector on an annual basis. For this analysis, the commercial rates for natural gas, electricity, and total energy for the commercial end-use sector and the total transportation energy rates are used, as shown in Table 5 (EIA, 2011).

	Rate ($/kbtu)
Building Energy	
Electricity	$0.030
Natural Gas	$0.009
Food Waste Energy	$0.012
Package Energy	$0.012
Last Mile Transportation	$0.021
End of Life Management	$0.012

Table 5: Energy cost rates by supply chain phase (EIA, 2011)

These rates are applied to the total energy use for each scenario to determine the economic impact of energy costs. For building energy use, the average distribution of energy use for electricity and natural gas is applied by building type, as shown in Table 6. These values are an average of fuel source distribution for each of the geographic locations used to estimate energy use for each building type, as described in the 'Building Energy' section of this chapter (Energy Star, n.d.).

Building Type	Electricity	Natural Gas
Grocery Store	72%	28%
Warehouse	65%	35%
Data Center	100%	0%

Table 6: Distribution of energy sources for building energy cost analysis (Energy Star, n.d.)

Total Emissions

Emissions is also tracked through all process to analyze the impact of a MK scenario relative to a traditional grocery outlet. While a standard price of carbon has not been established worldwide, many nations are moving toward carbon pricing as a means for controlling escalating emissions. As of 2016, more than 25 countries have implemented or scheduled for implementation regional or national carbon taxes or cap and trade systems. China, which is the largest single contributor to carbon emissions, has begun pilot carbon taxing programs in several urban areas of the country (World Bank, 2016). Thus, it is reasonable to estimate the overall economic impact of emissions because a carbon taxing system may be eventually implemented in some or all of the countries where MK services and grocery stores operate.

Pricing schemes vary significantly across countries and even regions within countries. In its State and Trends of Carbon Pricing report the World Bank has identified all pricing rates by country in US$ per ton of CO_2e. Rates ranged from $1 to $131 per ton of CO_2e, with 75% of the prices under $10 CO_2e (World Bank, 2016). The World Bank study is used to establish a min, most likely, and max carbon tax and modeled via Monte Carlo simulation using a triangular distribution. The modeled rate is then applied to the total emissions for each scenario to determine any economic differences based on emissions. While current carbon pricing rate schemes are a useful initial benchmark for pricing the impact of emissions, these rates may not fully capture the externalities associated with energy production and resource use. For example, the Environmental Protection Agency estimates the social cost of carbon to be between $11 to $56 per metric ton of CO_2e (depending on the discount rate used) (EPA, 2016). Thus, the estimated cost of carbon used in this analysis should be viewed as the lower bound of potential costs.

Other Operational Costs Differences

Economic differences between the two scenarios go well beyond energy and emission costs. Other operational expenses like labor, material costs, food costs, distributor markups, real estate, and other non-energy building costs like water may also be different depending on the supply chain model used. While this study does not seek to quantify all operational cost differences between the two models, these are nonetheless important considerations in evaluating whether MK services can have a measurable impact on the volume of food waste in the U.S. If MK services reduce food waste, the benefit of that reduction can only be realized if MK companies have a viable business model that can be used to serve a large market size.

Table 7 provides a brief assessment of potential economic differences between the two models beyond energy and emissions. Overall building management costs are likely higher under the grocery scenario, but labor needed to operate buildings may not be. While labor is required at each individual grocery store, MK services require labor to package and assemble the meal kits themselves. More details about MK service staffing requirements are necessary to evaluate labor costs differences between the two models.

MK service costs are higher under the last mile transportation scenario, but only because the Grocery scenario pushes the direct costs of this phase of transportation on to the customer. Product packaging costs will likely be higher under the MK scenario due to the overall larger amount of material required, specifically related to the shipping process. Each scenario will incur costs associated with food waste in their own facilities (the grocery store or the refrigerated warehouse), however it is expected to be higher under the Grocery scenario due to the larger volume of products offered and higher food waste rates overall. End of life material management for both scenarios is associated with total food and packaging waste, and thus the scenario with the larger volume of total waste will incur larger direct costs. Most of the direct costs associated with end of life material management are borne by the customer.

Category	Grocery	MK Services
Building	• Higher costs for real estate and other building related operation costs. More building space is required because more products are offered. • Potentially higher labor costs because of the decentralized service model (i.e. staff per neighborhood vs. one staffing location per region)	• Lower real estate and building operation costs due to less square foot required per meal – this is directly related to less product choice. • Potentially higher labor costs associated with the packaging and assembly process.
Last mile transportation	• Lower business costs because last mile transportation is paid for by the customer.	• Higher business costs because the company takes on the costs of last mile transportation.
Product packaging	• Lower packaging costs for grocery retailers because processed items are packaged by food sellers. Some packaging costs would likely be the same, for example produce and like meat that are packaged in store.	• Higher packaging costs–perhaps significantly—primarily driven by shipping materials like corrugate, ice packs, and insulation material.
Food waste	• Higher food waste costs in business operations due to more overall food volume and higher waste rates.	• Lower food waste costs due to lower food waste rates driven by better demand planning capability (because of the subscription model) and less product offerings.
End of life management	• Higher end of life costs for wasted food, lower end of life costs for packaging that remains in the building. Most end of life management cots are incurred by the customer.	• Lower end of life costs for wasted food, higher end of life costs for packaging that remains in the building (i.e. faulty materials) Most end of life management cots are incurred by the customer.

Table 7: Potential operational cost differences between the Grocery and MK Scenarios (beyond energy and emissions costs).

Analysis Results

Over the course of this study 521 food items were evaluated. Collectively, this food weighs 127 pounds and required 206 pounds of packaging under the MK scenario. Under the grocery scenario the total food weight is 352 pounds, requring 47 pounds of packaging.[6] This material is weighed and categorized to determine avoidable energy use, emission, and related costs using the methodology described in the previous section. The overall results include average, standard deviation, minimum, and maximum estimates for total energy, emission, and costs use under the Grocery and Meal Kit scenarios. The primary variance drivers are identified for both overall energy and emissions impacts, and individual categories of energy and emission sources (i.e. building energy, last mile transportation, etc.). These results are discussed in detail in the following sections.

TOTAL ENERGY AND EMISSIONS

Figures 3 and 4 shows the results of the total energy and emissions analysis, respectively. Average energy use in the MK Scenario is 20% lower than the Grocery Scenario and average emissions are 4% lower. The primary energy and emission drivers for each scenario are discussed below.

Grocery Scenario

The average energy use per meal under the grocery scenario is 39.25 kBtu and the average emissions per meal is 5.88 pounds of CO_2e. The average, median, and standard deviation for total energy use and emissions are shown in Table 36 in Appendix D. The primary variance drivers for both energy and emission are discussed independently in the sections below.

[6] Total packaging weight before adjusting for serving size.

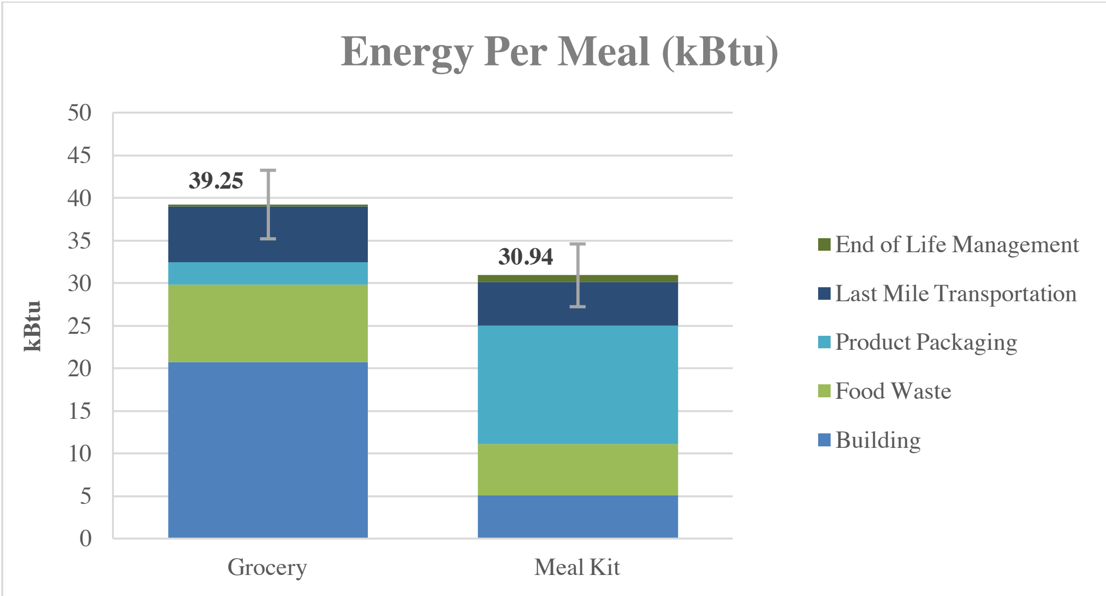

Figure 3: Total energy use per meal for the Grocery and Meal Kit Scenarios by energy use category. Number label is the total average and error bars are one standard deviation.

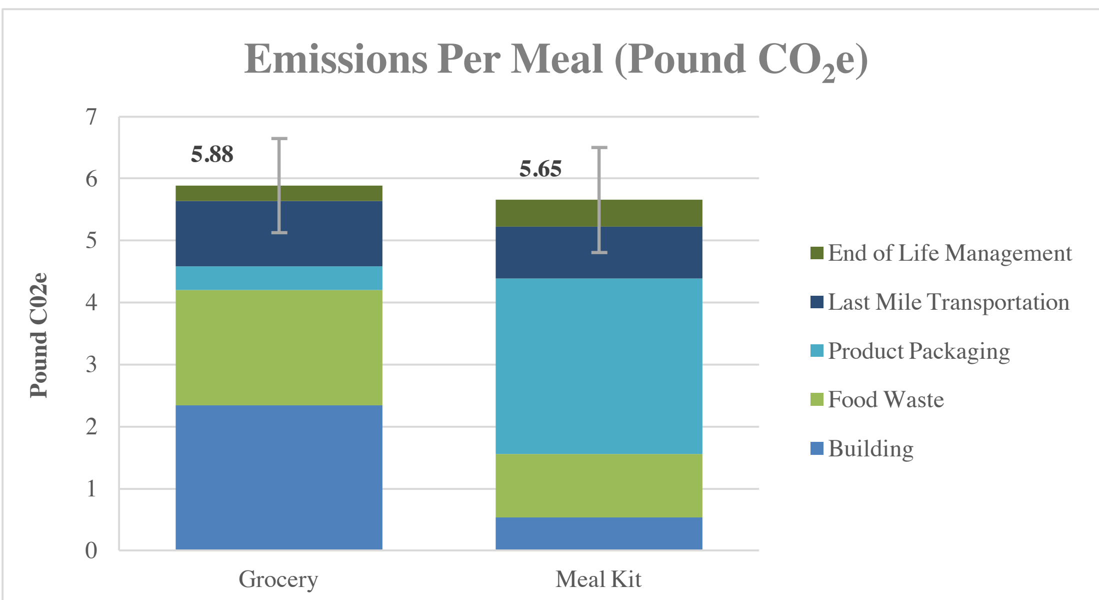

Figure 4: Total emissions per meal for the Grocery and Meal Kit Scenarios by emission source. Number label is the total average and error bars are one standard deviation

Energy

The share of energy use attributable to each category of consumption is shown in Figure 5. The top source of energy use in the Grocery scenario is the retail grocery store building, which makes up 53% of the energy use. The average Energy Use Intensity (EUI) for a grocery store in the U.S. is 480 kBtu/ft^2, trailing only convenience stores and fast food restaurants for the highest EUI of any commercial building type (Energy Star, 2016). Over 50% of the energy used in grocery stores is used for refrigeration and lighting (Energy Star-b, n.d.). While use of energy efficient and motion sensor lighting has helped decrease energy loads in some grocery chains, the industry standards for operating hours, facility size, and product offerings have made progress on energy efficiency slow.

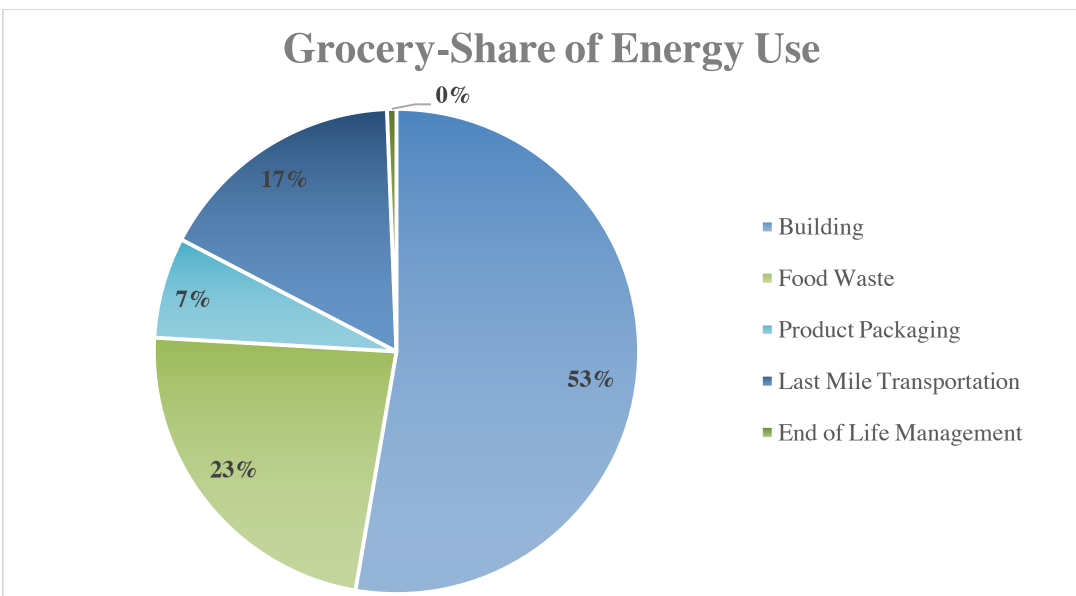

Figure 5: Share of energy use by source for Grocery Scenario.

The second highest energy source is the energy required to produce edible food that is wasted at the retail or household level, making up 23% of the total. The average weight of wasted food per meal is 12.62 ounces, driven by larger packaging sizes and waste rates at both the retail and household level. The food category contributing most to food waste is vegetable products, driven primarily by items that can both spoil and cannot be custom sized (i.e. a bag of spinach vs. a single tomato). Fruit, grains, and dairy are also top contributors to food waste by volume. The amount of food waste does not always directly correlate with energy use, however. While all these items contributed to energy use per meal (with 'Other Vegetables' being the highest single contributor), meat, poultry, and seafood contributed a higher portion when compared to total volume of waste because of the higher energy conversion factor per ounce.

Last mile transportation (LMT) makes up around 17% of the energy use for the MK Model. LMT has the most significant standard deviation compared to other impact categories, driven mostly by the round-trip distance between the local grocery store and the home which ranges from 0.2 to 25.2 miles, with an average of 5.2 miles. Thus, a consumer's location relative to a grocery store contributes significantly to overall energy use under the Grocery scenario. The lowest impact areas are Product Packaging (7%) and End of Life Product Management (<1%). The average packaging weight across all 50 meals measured is 3.8 ounces, dominated by glass, steel cans, and plastic materials like LDPE (produce bags) and PET (plastic bottles). Energy use for packaging is driven by the same materials. Finally, the total impact of end of life material management is minimal because very little energy is required to operate landfills, compost, recycling, and incineration facilities. In addition, the energy used to transport these items from the household to waste management facilities is nominal on a per-meal basis.

Emissions

The share of emissions attributable to each category of consumption evaluated is shown in Figure 6. Similar to energy use, retail grocery stores and wasted food production are responsible for the highest portion of emissions under the Grocery scenario. Emissions associated with operating grocery stores make up 40% of the total, while emissions from food waste make up 32%. The share of emissions from product packaging is slightly lower than the categories energy share (at 6%) and the emissions from Last Mile Transportation is slightly higher (at 18%). The energy use drivers discussed in the previous section generally apply to emission drivers for these categories as well. Energy conversation factors correlated closely with energy use for the materials and food items under the grocery scenario, except in the category of end of life material management.

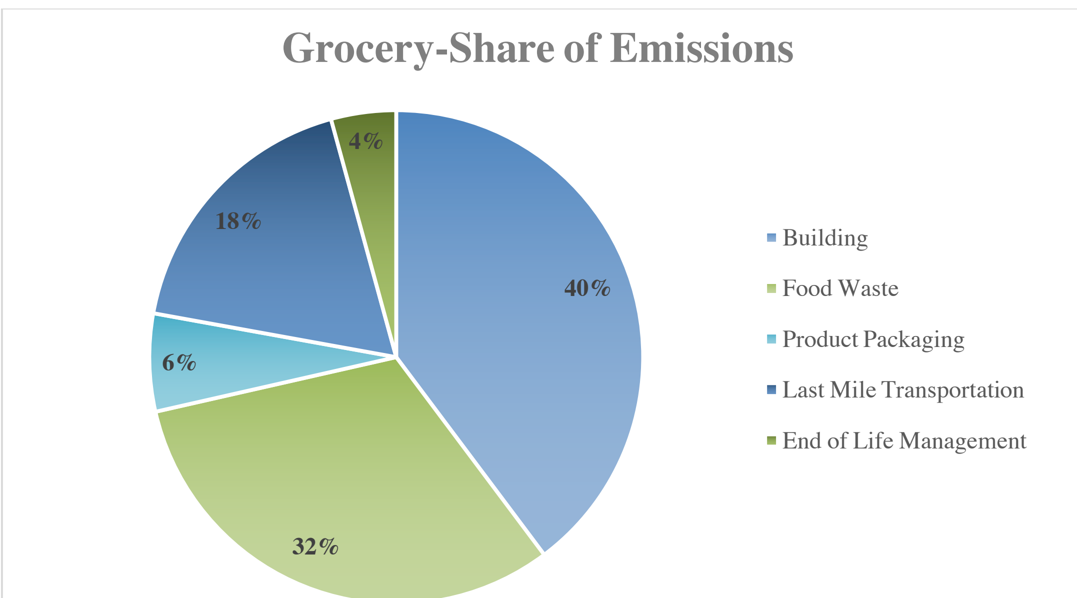

Figure 6: Share of emissions by source for Grocery Scenario.

End of Life Management (4% of total) varies most from the energy use share. The share of emissions is higher than energy use due to emissions generated at landfills and incineration plants. At landfills and compost facilities, paper and food products release greenhouse gasses. While this gas can be captured and converted to usable energy, only around 30% of landfills in the in the US are utilizing the technology that allows this (EPA, 2015). The emission factors for landfills takes into account the mix of traditional and methane capture facilities in operation today.

Meal Kit Scenario

The average energy use per meal under the MK scenario is 30.94 kBtu and the average emissions per meal is 5.65 pounds of CO_2e. The average, median, and standard deviation for total energy use and emissions are shown in Table 37 in Appendix D. The primary variance drivers for each category are discussed in the sections below.

Energy

The share of energy use attributable to each category of consumption evaluated is shown in Figure 7. The top source of energy use under the MK Scenario is product packaging at 45% of the total. The average packaging weight for a MK Meal is 4.1 pounds, driven primarily by ice pack filling, corrugate, and jute. Plastic products also contributed to the overall packaging weight, dominated by LDPE (plastic bags). The energy needed to produce both ice pack filling (which is predominately water) and jute is relatively low, thus corrugate and plastic contributes disproportionately to the energy intensity of product packaging compared to their relative weight under the MK scenario.

Average food waste is the next highest contributor at 19% of the total. The average food waste per meal under the MK scenario is 9.29 ounces. While the energy used to grow, process, and distribute wasted food is 34% less than under the Grocery scenario, the overall energy intensity of the food production process still has a measurable impact on total energy use in the overall MK service supply chain. Individual vegetable categories are the highest single contributors to average food waste per meal, followed by grains, fruit, and dairy. These items also contribute the most to wasted energy.

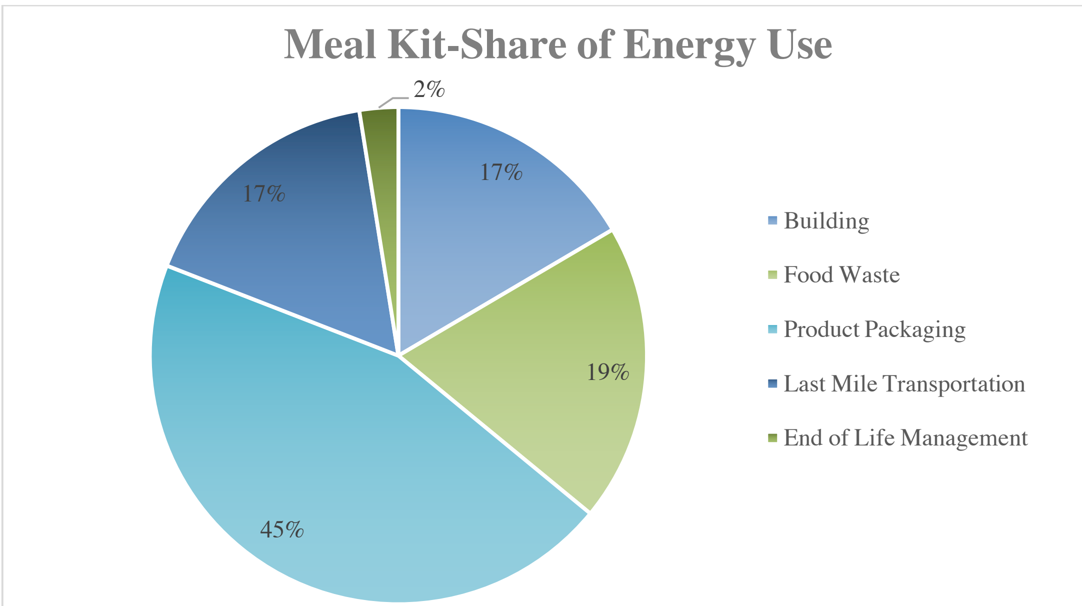

Figure 7: Share of energy use by source for MK Scenario.

Building Energy and Last Mile Transportation tie for the third highest source of energy use at 17% of the total for each category. Last mile transportation is driven by delivery mile per package, which varies depending on the geography of the specific delivery area. While the overall average distance traveled per meal is relatively low at 0.23 miles, less efficient vehicles and higher energy content of diesel fuel increases the impact of this phase of the MK supply chain. Building energy is driven primarily by refrigerated warehouses. While these buildings tend to be larger than a retail grocery store (median of 176,000 ft^2 vs. 17,500 ft^2 for grocery stores), their EUI is much lower. In addition, because the warehouses are processing meals for an entire region, the energy impact on a per meal basis is diluted compared to a grocery store which typically serves a neighborhood.

Like in the Grocery scenario, end of life management makes up the smallest portion of energy use under the MK Scenario at 2% of the total. The energy use included in this measurement is transportation from the household to the waste management facility, and energy use within the facility. Packaging materials are the primary drivers for this scenario's end of life management energy.

Emissions

The share of emissions attributable to each category of consumption under the MK scenario is shown in Figure 8. The proportional breakdown of emissions by category is different than energy use for all categories except Last Mile Transportation (15%) and Food Waste (18%). The share of emissions attributed to End of Life Material Management jumped to 8% of the total emissions. At landfills and compost facilities, paper and food products release a significant amount of greenhouse gasses. While this gas can be captured and converted to usable energy, only around 30% of landfills in the in the US are utilizing the technology that allows this (EPA, 2015). The emission factors for landfills (shown in Table 14, Appendix C) takes into account the mix of traditional and methane capture facilities in operation today. Overall, the volume of paper products—including corrugate—drove higher emissions under materials management.

Product packaging made up around 50% of total emissions for the MK scenario. This is proportionally higher than energy use because of the volume of paper products in the MK scenario. As discussed in the methodology section, the impact of deforestation on carbon storage is considered in the emission conversion factors for paper products. Including these emissions further exacerbates the impact of packaging in the overall environmental footprint of the MK scenario. Corrugate alone contributes an average of 1.72 pounds of CO_2e per meal, 30% of the total average emissions for all categories. Finally, the overall impact of buildings is around 9% of total emissions, driven down proportionally when compared to energy use by higher emissions in other categories.

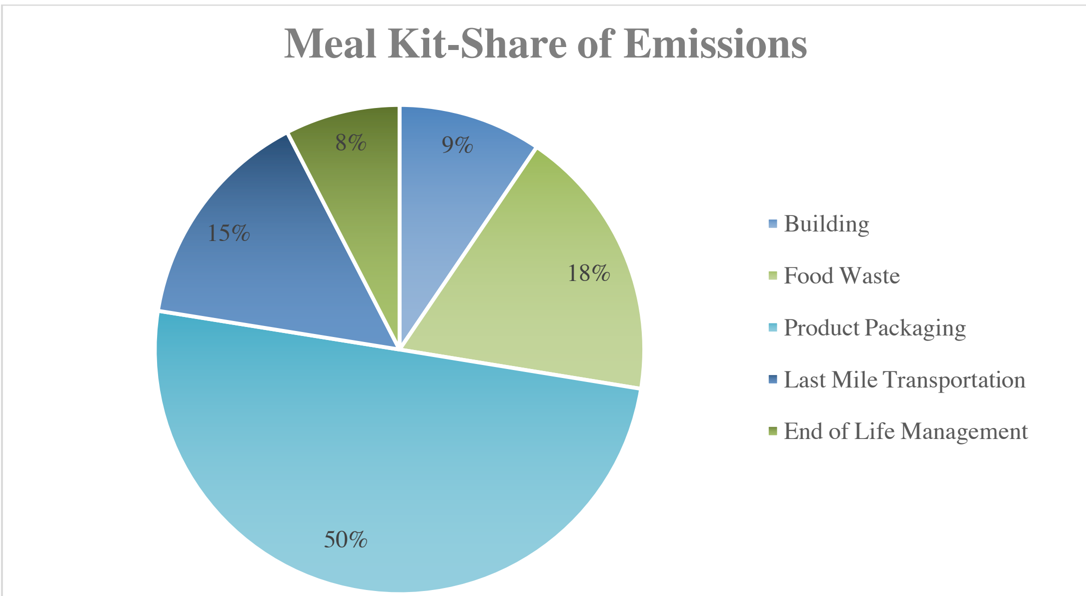

Figure 8: Share of emissions by source for MK Scenario.

COMPARING SCENARIOS BY ENERGY AND EMISSION SOURCE

Figures 9 and 10 show each Scenarios energy use and emissions generated by category. The MK scenario performs better than the Grocery scenario in three of the five categories. These three categories – building, food waste, and last mile transportation are also the top three contributors to energy use for both scenarios. The grocery scenario resulted in lower energy and emissions for both product packaging and end of life management. Each category is discussed in detail below.

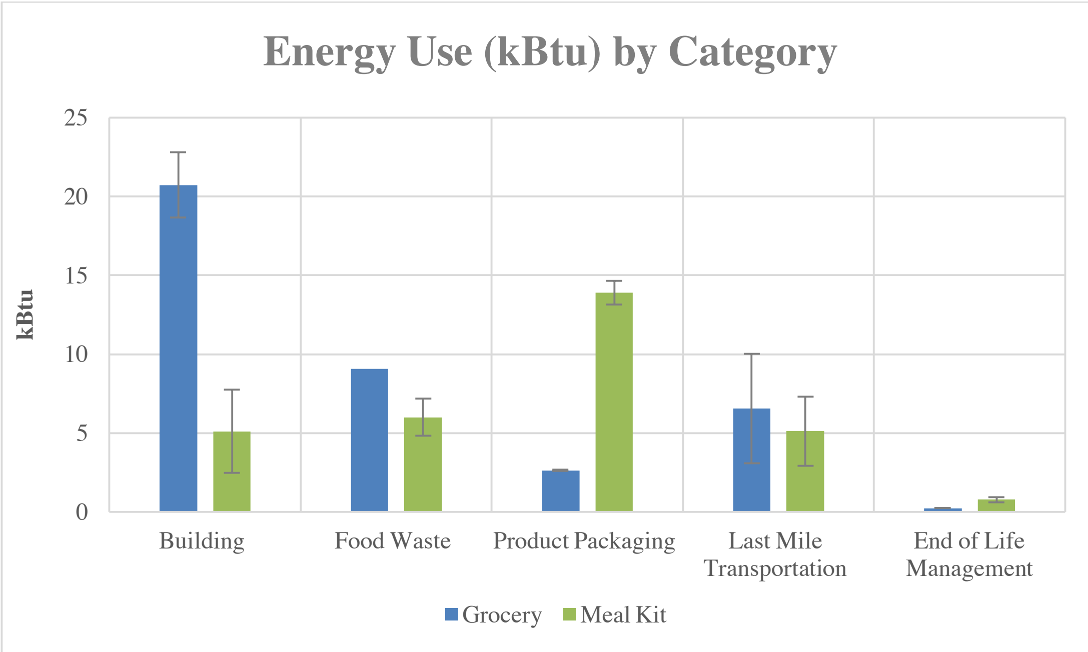

Figure 9: Energy use by category for Grocery and MK Scenario. Error bar is one standard deviation.

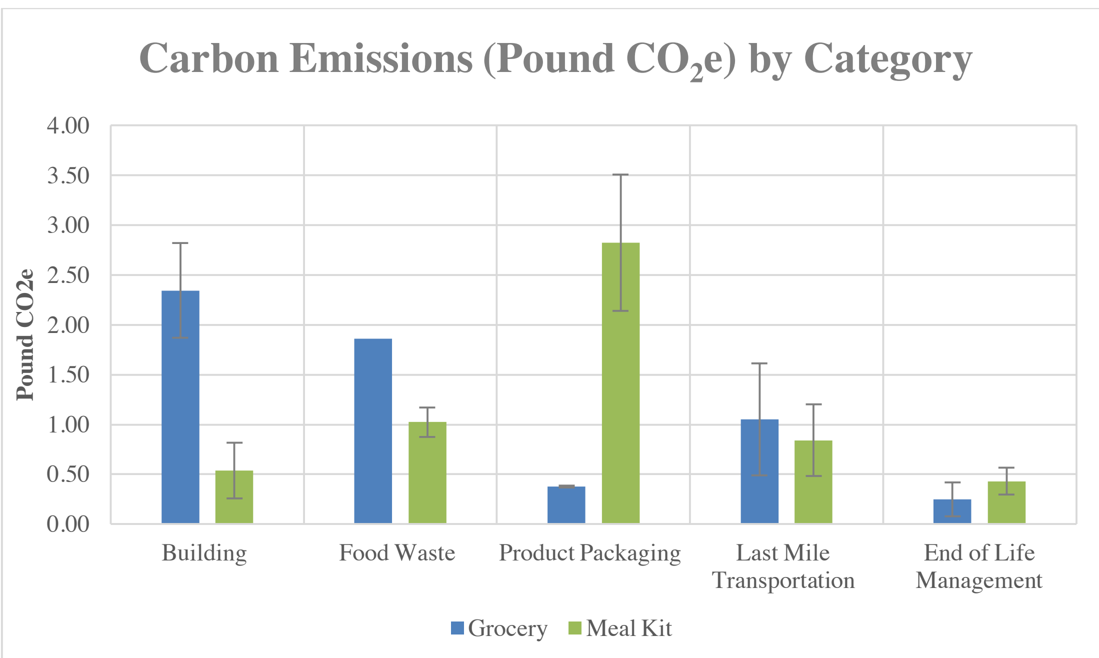

Figure 10: Emissions by category for Grocery and MK Scenario. Error bar is one standard deviation.

Building

Energy use and emissions are both around 75% lower under the MK Scenario. Building energy use is driven by three primary factors – Energy Use Intensity (EUI) for the property type, the overall size of the facility, and the volume of meals processed through the facility. MK Service can achieve relatively low building energy use compared to a grocery store because they perform better in two out of three of these areas. First, the EUI (in annual kBtu/ft^2) of a refrigerated warehouse is half that of a grocery store. While refrigeration itself is generally energy intensive—and in fact contributes significantly to the EUI for grocery stores—refrigerated warehouses are designed to maintain a refrigerated state for 24-hours a day and thus do not have go through the energy intensive process of ramping the cooling system throughout the day. This combined with minimal windows, less direct exposure to outdoor air, and advanced building envelopes that help keep out external heat sources results in an overall lower EUI than other food service establishments.[7]

Finally, the overall volume of meals processed through a MK warehouse is a higher than a typical grocery store because they serve a larger market. Where a grocery store might cater to an individual neighborhood, MK services tend to have three regional locations within the US. Economies of scale are also the reason data center energy use makes up such a small portion of energy use in the MK Scenario (0.2%). As MK services grow, maintaining the benefit of scale will be important to keeping building energy use and emissions low.

[7] The min, max, and most likely EUI used for a refrigerated warehouse in this study is based on a range of geographies to account for the impact of external climate (like warmer climates) on energy use.

Food Waste

Energy and emissions from the production of food that is wasted is 34% and 45% lower under the MK scenario, respectively. Similarly, the overall volume of food waste is on average 27% lower on a per meal basis than the Grocery scenario. The food categories driving food waste also differ between the two models. Other vegetables top both lists, but under the Grocery scenario starchy, red and orange, and dark green vegetables round out the top 4. Alternatively, the MK scenario was led by grains, fruit, and red and orange

Grocery		Meal Kit	
Total Food	Wasted Food	Total Food	Wasted Food
Other vegetables	Other vegetables	Other vegetables	Other vegetables
Grains	Red and orange vegetables	Red and orange vegetables	Grains
Dairy	Starchy Vegetables	Starchy vegetables	Dark green vegetables
Red and orange vegetables	Dark green vegetables	Dark green vegetables	Red and orange Vegetables
Dark green vegetables	Grains	Grains	Fruit
Energy	Emissions	Energy	Emissions
Other vegetables	Meat	Other vegetables	Other vegetables
Meat	Seafood	Grains	Meat
Seafood	Poultry	Dark green vegetables	Dairy
Red and orange vegetables	Other vegetables	Red and orange Vegetables	Grains
Starchy vegetables	Dairy	Fruit	Fruit

Table 8: Top food volume, waste volume, energy, and emission categories for the Grocery and MK scenarios.

vegetables. The total portion of vegetables by starting weight also varied across the two models, at 72% of the food under the MK scenario and 62% under the Grocery scenario. The overall increase in starting food weight is further exacerbated by the higher food waste rate under the Grocery scenario. The household food waste rate averaged 5.07% under the MK model and 22.7%[8] under the Grocery scenario (both figures are weighted

[8] Food waste rates under the Grocery Scenarios were not measured manually but instead based on USDA LAFA averages. These rates were then weighted by food category volume to develop a weighted average.

by food category volume). Food waste alone does not translate directly to energy use emissions, as energy and emission conversion rates vary by food category. Table 8 shows the top contributors to energy and emissions under each scenario, as well as the top overall food categories by volume.

Product Packaging

Product packaging impact is driven by the volume, the recycled content, and energy and emission conversion rates by material type. Product packaging energy and emissions are significantly higher under the MK scenario—energy use is 428% higher and emissions are 625% higher than the Grocery scenario. The 50 MK service meals generated 206 pounds of packaging material total, which results in an average of around four pounds per meal. In contrast, packaging weight under the grocery scenario averaged 0.23 pounds per meal. MK packaging weight is driven predominately by a few materials: Ice Pack Filling (70%), Jute (5%) and Corrugate (14%). The remaining materials are a mix of plastics (primarily LDPE resins, which are plastic bags), other paper products, and metals. Ice pack filling and jute are estimated to have a minimal energy and emission impact (see methodology section for details), meaning items with a much smaller share of the total weight are also driving energy and emissions under the MK scenario. The share of recycled material used in the final packaging product drives emission and energy conversion rates because using recycled material requires less resources than using virgin materials. This is especially true for emissions related to paper products because deforestation leads to a decline in carbon sequestration potential and thus an overall higher emission impact.

Last Mile Transportation

The MK scenario had a modest advantage over the grocery scenario for last mile transportation, with 22% lower energy use and 20% lower emissions. These findings are on the low end of other studies that have evaluated the energy and emission differences in e-commerce versus retail shopping. For example, one study found that e-grocery shopping can reduce emissions by up to 75% (the same study found that the low end of emissions savings is 20%) (Wygonik & Goodchild, 2012). The relatively lower difference between the two scenarios evaluated here can be attributed to the limited number of meals delivered via the MK service model versus a grocery store trip. Most MK services offer a standard volume of three meals per delivery. The traditional grocery store shopper visits a retail establishment around 1.8 times per week and purchases around 14 meals worth of food per week during these trips. Thus, the overall miles traveled per meal ends up being only slightly lower under the MK service model.

End of Life Management

Energy and emissions associated with end of life material management are both lower under the MK scenario, by 219% and 72% respectively. In addition, the overall waste material generated between the two scenarios is significantly different. Under the MK scenario over 4.75 pounds of material require management per meal, while only 1.03 pounds require management under the Grocery scenario. Most the weight in the MK service packaging is ice pack filling, which could conceivably be disposed of in the home (or better, reused). Removing ice pack filling from the MK service weight results in an overall per meal material weight of 1.85 pounds (still 80% higher than the Grocery scenario). However, human behavior suggests that some consumer may decide to send used icepacks to the landfill or incineration facility once they have accumulated enough for reuse in the household. In addition, the material management method used also played a role in the total energy and emissions for each scenario. Higher recycling rates reduced overall energy and emissions for packaging materials. Use of combusting facilities also resulted in an overall lower emission impact for most materials except plastics, which have a significantly higher emission rate under the combustion scenario compared to other material management approaches. Similarly, composting rates drove higher emissions benefits for food waste because of the negative emission factor associated with this material management approach. While the share of material management approaches is consistent across both scenarios, the overall higher volume of material under the MK scenario exacerbated the impacts of less efficiency material management approaches.

ECONOMIC IMPACT

The economic impact of these can be evaluated through a lens of overall energy and emissions savings. The collective energy and emissions costs measure the economic impact of each scenario. Since there is not a widespread carbon tax policy in the U.S. currently, energy and emissions costs are calculated separately and summed. The likely beneficiary of these savings – business or customers – is discussed in the Implications chapter of this report. Figure 11 shows energy and emissions costs under each scenario using the total energy and total emissions methods. The total energy and emission costs per meal is \$0.93 in the Grocery scenario and \$0.62 in the MK scenario.

As discussed in the methodology section, economic differences between the two scenarios go well beyond energy and emission costs. Other operational expenses like labor, material costs, food costs, distributor markups, real estate, and other non-energy building costs like water may also be different depending on the supply chain model used. While this study does not seek to quantify all operational cost differences between the two models, these are nonetheless important considerations in evaluating whether MK services can have a measurable impact on the volume of food waste in the U.S. The next chapter discusses the implications of these potential cost differences (as identified in Table 5, Methodology).

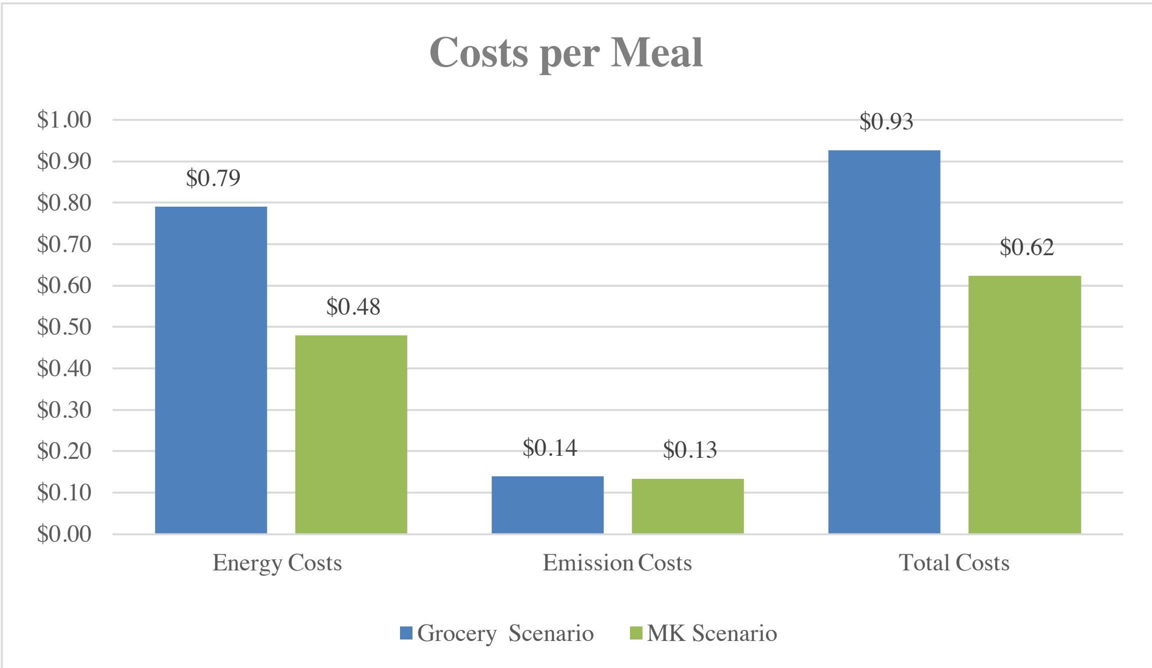

Figure 11: Economic impact of energy use and emissions under the MK and Grocery scenario.

Implications

This analysis suggests that on a per meal basis energy and cost savings are likely under the MK scenario and emissions savings are possible. The collective impact of these savings will depend on the growth of MK service-like models going forward, and each company's ability to scale while still maintaining cost efficiencies and environmental benefits. The impact of one household using a MK service for the standard three dinners a week over the course of a year is relatively minor from an energy, emissions, and cost savings perspective (as shown in Figure 12). The environmental impact is equivalent to saving between 1.7 and 28.3 gallons of fuel (depending on if you use energy or emissions savings as the measure) (EPA, 2016), and the energy and emission cost savings are under $50. In addition, nearly 19 times the weight of food savings is generated in the form of packaging waste.

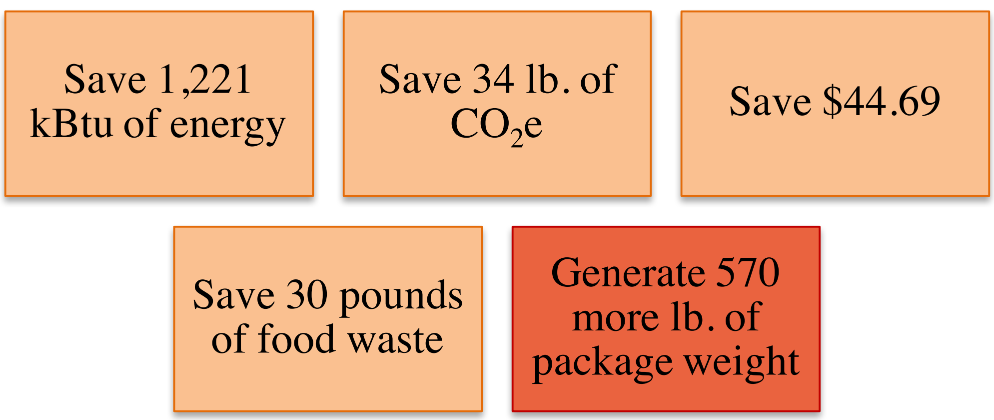

Figure 12: Annual MK savings and costs for one household. Assumes 3 meals per week for 49 weeks.

While the annual household savings are relatively minor, the aggregate benefit of multiple households using a MK service could be substantial. For example, if 1% of

American households[9] used a MK service for 49 weeks per year, the annual energy savings would be equivalent to powering 33,416 homes for a year (EPA, 2016), and the overall financial benefit would be $56 million. It would also save enough food to feed 19,300 people for a year.[10] Like most innovations, there are tradeoffs for these benefits. This same scenario would generate an additional 2.41 million tons of waste, equal to around 1% of the waste generated by households in 2014 (EPA, 2016). The environmental impact of this increase can be minimized if these post-consumer materials are diverted to their next best use through recycling or composting.

The benefits of these cost savings are not borne by customers or businesses alone. Table 9 provides an overview of who benefits from energy cost savings at different phases of the supply chain. MK Services receive a greater share of the benefit from energy savings, but also take on a lion's share of increases in energy use associated with product packaging. Food waste savings benefit both customers and MK service companies, as well as the food sector overall. Although households experience the most benefit in terms of the volume of food saved (88% of food waste savings by weight), the precise financial beneficiary is more complex because MK services can cost more than a typical meal prepared at home using materials purchased from the grocery store. MK services on the other hand directly benefit from food waste savings as margins increase when product waste declines. Although customers take on increased energy use associated with end of life management, they typically pay a fixed rate for waste hauling services and thus would not experience a direct increase in cost. However, waste management companies would experience an increase in volume that could increase costs. These costs may ultimately be passed on to customers in the form of rate increases

[9] Assumes 125.8 million households in the U.S. (U.S. Census, 2016)
[10] Assumes average daily food intake of 5.46 pounds (USDA ERS, 2014)

or government subsidies to maintain existing rates. Finally, by using a delivery service customers avoid any expenses associated with last mile transportation. Thus, their direct cost savings are likely greater than the $4.41 of energy savings attributed to that phase of the supply chain. Evaluating energy costs savings from this perspective suggests that MK services, grocery stores, and customers have opportunities to decrease energy costs.

	Energy Cost (Savings) and Increases	Beneficiary
Building	$(56.08)	MK Service
Food waste	$(5.44)	Food Industry
Packaging	$20.54	MK Service
Last mile transportation	$(4.41)	Customer
End of life management	$0.95	Waste Managers

Table 9: Annual energy cost savings and increases per customer under MK scenario and the beneficiaries.

The public health benefit of lower food waste is an important consideration not captured in direct cost savings. An estimated 42.2 people in the U.S. are food insecure, and 31% of the food insecure population are children (Feeding America, n.d.). Food insecurity has been linked to higher health care costs. A study by Valerie Tarasuk and Craig Gundersen found that health care costs are between 49% and 121% higher for people with low food security (Waxman, 2015). In addition, a study by Hilary Seligman found that in the U.S. hospital admissions for hypoglycemia are 27% higher in the last week of the month for low income patients (there is no change for high income patients). Researchers speculate the increase could be attributed to lower food supplies towards the end of the month as disposable income dwindles for low, fixed income households (Waxman, 2015). Although it would take a substantial MK service adoption rate to make a measurable difference in food insecurity in the U.S., the problem is great enough that any positive step towards reducing food waste is critical.

WHAT NEXT?

These findings represent the current—not the ideal— state of the grocery and MK service supply chain model. While there are clear benefits to each of the models, companies in both industries can take additional steps to reduce energy use and emissions and their related costs throughout their supply chain. The following recommendations address opportunities for both grocers and MK services.

Recommendations for MK Services

MK services have a clear advantage in several of the energy use and emissions categories evaluated. As MK service companies grow they will have the opportunity to both maintain their existing advantages while also minimizing impacts. Some actions these companies can take to both save energy and reduce emissions (where the benefit of the MK service model is less clear) are:

- Reduce the overall quantity of shipping packaging. The weight of corrugate boxes for the four MK services evaluated ranged from 1.1 to 2.9 pounds. Using the lower weight box results in an energy savings of 6.3 kBtu per meal and an emission savings of 1.76 pounds of CO_2e per meal.
- Use lower impact materials in all packaging. The use of jute as an insulator in around 50% of the MK service boxes evaluated is an example of an action already being taken that reduces carbon emissions (compared to the plastic and aluminum material that is used as an insulator in some boxes). MK services should seek out and/or invest in development of alternate material technologies to reduce the use of virgin paper products that lead to deforestation.

- Use high recycled content material whenever possible. The difference in energy costs between using a 100% recycled corrugate box versus a 35% recycled content (the current average) box is 2.58 kBtu per meal and the emissions savings are 0.93 pounds of CO_2e per meal.
- Create opportunities for customers to recycle product packaging easily. LDPE bags are a common material in many MK service boxes, but typically are not accepted in municipal curbside recycling program. Blue Apron is piloting a solution for this by allowing customers to ship discarded packaging materials—including ice packs—back to the company (Blue Apron, n.d.).

Recommendations for Grocers

While the grocery scenario came out behind the MK scenario in most of the energy and emission metrics evaluated in this study, these businesses also have the most to gain from understanding the benefits of the MK service model and using them in their own operations. Some actions these companies can take to leverage their advantages and lessen the impact of their disadvantages are:

- Prioritize building energy efficiency to reduce the total energy consumed in the retail environment. Energy Star estimates that in the grocery sector $1 dollar in energy savings is equivalent to increasing sales by $59 because of the low margins in the industry (Energy Star-b, n.d.).
- Reduce product offerings to eliminate the unnecessary energy use associated with maintaining the quality and freshness of slow-moving products. According to a year-long study by Catalina Marketing, a typical customer purchases less than 1% of available products in a grocery store (Marketing Charts, 2014).
- Repurpose potential food waste by using it in prepared items before it spoils.

- Encourage customers to bring their own reusable bags to further reduce product packaging waste.
- Use composting and recycling services to dispose of waste generated in the store.

Leveraging the Best of Both Models

The most substantial opportunity for energy and emissions savings would come from collaboration across the grocery and MK service industries. Leveraging the best of each model could provide benefits for both companies. For example:

- MK services can use grocery stores as a delivery location. Since their customers likely visit the grocery store weekly to purchase other food eaten in the home, they could avoid increasing the number of grocery trips while reducing packaging requirements. Shipping in bulk to a single grocery store location would allow for decreased energy costs for delivery while also reducing the amount of packaging required. Instead of packaging kits in individual boxes with their own insulation and ice packs, customers can pick up packaged kits in the refrigerated section and take them home using their own reusable bags.
- Grocery stores can use food in the grocery store to create MKs options for customers. By using anticipated surplus food in standard MK recipes, grocers can reduce food waste while also increasing the convenience of shopping for their customers. A company called Handpicked sells kit recipes and services that help grocers implement this model.

LIMITATIONS AND OPPORTUNITIES FOR ADDITIONAL RESEARCH

While these findings represent the most comprehensive analysis of the MK service model to date, there are limitations to these findings that can be addressed in further research as additional data becomes available or methodologies are improved. A significant drawback to this research is that does not consider differences in the upstream portion of each scenarios supply chain. The potential impact of direct, local sourcing (versus purchasing through wholesale suppliers) and the subscription based business model on overall supply chain food waste warrants additional evaluation as better data becomes available. The specific characteristics of different MK services may also play a role in overall energy and emission use. For example, GreenChef uses predominately USDA organic products, the benefits of which are not evaluated in this study. However, their role in distributing organic products that may not be available locally could have additional environmental benefits. Further research into this topic could also explore other environmental metrics, like water and land use. In addition, quantifying the other operational costs differences between the two models would provide a fuller picture of the viability of the business model going forward, and whether it can be price competitive with at home meal preparation for lower income households (which would significantly expand its target market) in the future. Lastly, and perhaps most significantly, further research is needed to evaluate the relative benefit of MK services compared to alternatives beyond the 'grocery-equivalent' scenario, like visiting a restaurant or fast food establishment or preparing a meal at home using a different recipe.

Appendices

APPENDIX A: MK RECIPES

Plated	
Seared steak	Fontina and brie grilled cheese
Chicken empanadas	Moroccan chickpea stew
Poached fish	Vegetable tostadas
Turkey meatloaf	Cheesy eggplant pizza melts
Steak Heroes	Crispy quinoa hash
Trout picatta	Gnocchi parmesan broth
Blue Apron	
Indonesian salmon	Sunchoke & egg noddle casserole
Pibil style pork	Potato & broccolini samosas
Seared chicken	Vegetable bibimap
Steak with peppercorn sauce	Brown butter and chestnut gnocchi
Cod en papillote	Spiced lentil stew
Sesame chicken	Spinach and ricotta pizza
Thai green coconut curry	Spicy black rice noodles
Hello Fresh	
Roasted red peppers	Kale and quinoa salad
Italian meatloaf	Yellow squash flatbreads
Salsa spaghetti	Sweet potato and black bean tacos
Catch of the day cod	Tuscan ribollita
Shepherd's pie	Mushroom lo mein
Little ears pasta	Oven roasted cauliflower
Green Chef	
Ancho-herb steak	Greek pasta bowl
Broccoli gratin and steak	Five spice sweet potato
Thai chicken tacos	Moroccan veggie couscous
Mediterranean tuna	Butternut squash chili
Harissa-honey chicken	Thai Portobello steak
Garlic shrimp	Durban bunny chow

Table 10: MK recipe list by MK service company.

APPENDIX B – PRODUCT PACKAGE MATERIAL DEFINITIONS

Packaging Material	Description
Paper Products	
Corrugated Containers[11]	Corrugated container boxes made from containerboard (liner and corrugating medium) used in packaging applications.
Magazines/Third Class Mail[12]	Third Class Mail is now called Standard Mail by the U.S. Postal Service and includes catalogs and other direct bulk mailings such as magazines, which are made of coated, shiny paper. This category represents coated paper produced from mechanical pulp.
Office Paper[13]	Office paper represents paper made from uncoated bleached chemical pulp.
Mixed Paper (Residential)	Residential mixed paper is assumed to be 23% newspaper, 53% corrugated cardboard, 10% Definition magazines and 14% office paper (Barlaz, 1998).
Plastics	
HDPE	HDPE (high-density polyethylene) is usually labeled plastic code #2 on the bottom of the container, and refers to a plastic often used to make bottles for milk, juice, water and laundry products. It is also used to make plastic grocery bags.
LDPE	LDPE (Low-density polyethylene), usually labeled plastic code #4, is often used to manufacture plastic dry cleaning bags. LDPE is also used to manufacture some flexible lids and bottles and plastic grocery bags.
PET	PET (Polyethylene terephthalate) is typically labeled plastic code #1 on the bottom of the container. PET is often used for soft drink and disposable water bottles, but can also include other containers or packaging.
PS	GPPS (General Purpose Polystyrene) has applications in a range of products, primarily domestic appliances, construction, electronics, toys, and food packaging such as containers, produce baskets, and fast food containers.
Mixed Plastics	Mixed plastics are made up of a weighted average of 39% HDPE and 61% PET plastic.
Glass Container	Glass represents glass containers (e.g., soft drink bottles and wine bottles).

[11] The corrugated containers category is used to proxy tissue paper and towels, paper plates and cups, other non-packaging paper and corrugated boxes.

[12] The magazines/third-class mail category is used to proxy magazines and standard mail.

[13] Office paper is used to proxy books, office-type papers, other commercial printing, milk cartons, folding cartons, other paperboard packaging, bags and sacks, and other paper packaging.

Packaging Material	Description
Ice Pack Filling	Ice pack filling is typically 99% water and 1% polyacrylate (C. F., Green Chef, personal communication, November 10, 2016)
Jute	Jute is a vegetable fiber that can be spun into threads. The material is woven into a 1 or 2-inch blanket, and is then wrapped around ingredients and icepacks to help serve as an insulator.
Aluminum Cans	Aluminum cans represent cans produced out of sheet-rolled aluminum ingot.
Steel Cans	Steel cans represent three-piece welded cans produced from sheet steel that is made in a blast furnace and basic oxygen furnace (for virgin cans) or electric arc furnace (for recycled cans).

Table 11: Packaging material descriptions. All descriptions except Jute and Ice Pack filling are adapted from Exhibit 1-2 and footnote 112 in the EPA WARM Documentation (EPA, 2015).

Appendix C: Methodology Data

Energy and Emission Conversion Factors

Food Category	kBtu/ounce	lb. CO_2e/ounce
Fruit	0.56	0.08
Vegetables	-	
Dark Green	0.64[14]	0.03
Red and Orange	0.64[14]	0.05
Legumes	0.54	0.10
Starchy	0.64[14]	0.03
Other	0.64[14]	0.06
Grains	0.52	0.06
Protein	-	
Seafood	1.56[15]	0.39
Meat	1.56[15]	1.17
Poultry	1.56[15]	0.33
Eggs	1.15	0.25
Nuts	0.48	0.11
Dairy	0.52	0.18
Oils	0.40	0.45
Fats	0.40	0.13
Sugar	0.41	0.10

Table 12: Energy and emission factors for food production and upstream transportation by food category. Energy factors based on Cuellar and Webber (2010) and scaled to present day using USDA (2014) and EIA (2014). Emissions factors based on Heller and Keoleian (2015) and EPA WARM (2015).

[14] Calculated together based on data availability
[15] Calculated together based on data availability

	Energy		Emissions	
	kBtu/ounce		lb. CO_2e/ounce	
Material	Virgin	Recycled	Virgin	Recycled
Paper Products				
Corrugated Containers	0.85	0.41	See Table 14 for Modeled Ranges	0.06
Magazines/Third Class Mail	1.04	1.01		0.11
Office Paper	1.16	0.64		0.09
Mixed Paper	1.01	0.40		0.05
Plastics	-	-		
HDPE	0.81	0.25	0.11	0.04
LDPE	0.97	0.02	0.06	0.00
PET	0.94	0.47	0.16	0.07
Mixed Plastics	0.89	0.38	0.14	0.13
Glass Container	0.23	0.16	0.04	0.02
Ice Pack Filling	0.02	0.00	0.00	0.00
Jute	0.00	0.00	0.00	0.00
Aluminum Cans	5.81	1.16	0.77	0.14
Steel Cans	1.14	0.40	0.25	0.07

Table 13: Energy and Emission conversion rates for packaging products made from virgin and recycled materials. All data from EPA WARM (2015).

	lb. CO_2e/ounce		
Material	Min	Most Likely	Max
Corrugated Containers	0.06	0.31	0.56
Magazines / Third Class Mail	0.11	0.36	0.61
Office Paper	0.07	0.31	0.57
Mixed Paper	0.09	0.34	0.58

Table 14: Modeled ranges for production of virgin paper products. Based on EPA WARM (2015).

	Recycling Energy Factor	Landfill Energy Factor	Compost Energy Factor	Combustion Energy Factor
Material	kBtu/ounce			
Paper Products				
Corrugated Containers	0.01	0.02		0.01
Magazines / Third Class Mail	0.01	0.02		0.01
Office Paper	0.01	0.02		0.01
Mixed Paper	0.01	0.02		0.01
Plastics				
HDPE	0.01	0.02		0.01
LDPE	0.01	0.02		0.01
PET	0.01	0.02		0.01
PS	0.01	0.02		0.01
Mixed Plastics	0.01	0.02		0.01
Glass Container	0.01	0.02		0.01
Ice Pack Filling	0.01	0.02		0.01
Jute	0.01	0.02		0.01
Aluminum Cans	0.01	0.02		0.01
Steel Cans	0.01	0.02		0.01
Food Waste	0.00	0.02	0.018	0.01

Table 15: Energy use rates for four material management options. Based on EPA WARM (2015)

Material	Recycling Emission Factor	Landfill Emission Factor	Compost Emission Factor	Combusted Emission Factor
	lb. CO_2e/ounce			
Paper Products				
Corrugated Containers	0.00	0.03		-0.03
Magazines / Third Class Mail	0.00	0.05		-0.02
Office Paper	0.00	0.10		-0.03
Mixed Paper	0.00	0.02		-0.03
Plastics				
HDPE	0.00	0.00		0.09
LDPE	0.00	0.00		0.09
PET	0.00	0.00		0.09
PS	0.00	0.00		0.12
Mixed Plastics	0.00	0.00		0.09
Glass Container	0.00	0.00		0.00
Ice Pack Filling	0.00	0.00		0.00
Jute	0.00	0.00		0.00
Aluminum Cans	0.00	0.00		0.00
Steel Cans	0.00	0.00		-0.11
Food Waste	0.00	0.05	-0.01	-0.01

Table 16: Emission rates for four material management options. Based on EPA WARM (2015)

	Energy (kBtu/ft^2)			Emissions (lb. CO_2e/ft^2)		
Building Type	Min	Most Likely	Max	Min	Most Likely	Max
Refrigerated Warehouse	156.80	202.50	336.7	13.69	23.72	35.66
Data Center	158.00			6.00	11.80	27.00
Supermarket/Grocery Store	536.8	636.9	724.6	38.19	76.13	103.78

Table 17: Energy and emission rates by building type. Based on Energy Star (n.d.) data for 15 (Warehouse and Supermarket) and 8 (Data Center) building locations.

	Energy
Fuel Type	**kBtu/Gallon**
Regular Unleaded Gasoline	120.48
Diesel Gasoline	137.38

Table 18: Energy rates per gallon of fuel. Based on EPA data (2014)

Gasoline / Passenger Vehicle		
GHG	*Emission Factor*	*Unit*
CO^2	19.357	lb. CO_2e/gallon
NH^4	0.0010	lb. CO_2e/mile
N^2O	0.0024	lb. CO_2e/mile
Diesel / Mid-Size Truck		
GHG	*Emission Factor*	*Unit*
CO^2	22.509	lb. CO_2e/gallon
NH^4	0.0003	lb. CO_2e/mile
N^2O	0.0032	lb. CO_2e/mile

Table 19: Emission rates by fuel type and vehicle type. Based on EPA data (2014)

Building Data

	Building Size (ft^2)		
Building Type	Min	Most Likely	Max
Refrigerated Warehouse	10,000	176,000	900,000
Data Center	250	1,000	10,000
Supermarket/Grocery Store	1,250	17,500	150,000

Table 20: Min, median and max building sizes by building type based on EIA 2012 Commercial Building Energy Consumption Survey (EIA, 2012).

	Min	Most Likely	Max
Cost per meal ($/meal)	$14.86	$18.27	$21.98

Table 21: Min, average, and max grocery equivalent costs per meal for MK service ingredients (Yates, 2016).

	Meals Processed (2 serving meal)		
Building Type	Min	Most Likely	Max
Refrigerated Warehouse	12,000,000	16,000,000	20,000,000
Data Center	36,000,000	48,000,000	60,000,000

Table 22: Minimum, most likely, and max meals processed per MK service facility. Based on public statements that Blue Apron processes 8,000,000 servings per month (Griffith, 2016). Total meals are assumed to be equally distributed across three distribution centers. All meals are assumed to be electronically processed through one data center.

Last Mile Transportation Data

	Min	Most Likely	Max
RT distance to grocery store (miles)	0.2	5.23	24.6
Weekly trips to grocery store	1.5	1.85	2

Table 23: Min, most likely, and max values for variables in Grocery scenario last mile transportation. Miles to grocery store based on research by Liu published by the CDC (CDC, 2015). Weekly trips based on 10-years of trip data as published by FMI (FMI, 2016).

	Min	Most Likely	Max
MK Delivery miles/package (miles)	0.07	0.56	1.6

Table 24: Minimum, most likely, and max delivery miles per MK Service package. Based on four separate research studies by Siikavirta, Weber, Weideli, and Goodchild. (Siikavirta, 2003)(Weber, 2008)((Weideli, n.d) (Wygonik & Goodchild, 2012)

Product Packaging Data

	Min	Most Likely	Max
Paper Products			
Corrugated Containers	10%	35%	100%
Magazines / Third Class Mail	0%	4%	30%
Office Paper	0%	4%	35%
Newspaper	0%	23%	60%
Mixed Paper	0%	25%	60%
Plastics			
HDPE	0%	10%	15%
LDPE	0%	0%	0%
PET	0%	3%	10%
LLDPE	0%	0%	0%
PP	0%	0%	0%
PS	0%	0%	0%
PVC	0%	0%	0%
Mixed Plastics	0%	6%	0%
Glass Container	5%	23%	30%
Ice Pack Filling	0%	0%	0%
Jute	0%	0%	0%
Aluminum Cans	0%	68%	100%
Steel Cans	20%	33%	50%

Table 25: Minimum, most likely and max recycled content for product packaging by material type. Based on EPA WARM documentation (EPA, 2015).

	(ounces)	
Packaging Material	Meal Kit Scenario	Grocery Scenario
Paper		
Corrugated Containers	9.14	0.00
Magazines / Third Class Mail	1.15	0.00
Office Paper	0.10	0.03
Mixed Paper (Residential)	0.29	0.01
Plastics		
HDPE	0.28	0.07
LDPE	3.76	0.93
PET	0.83	0.44
PS	0.00	0.06
Mixed Plastics	0.24	0.18
Glass Container	0.09	1.25
Ice Pack Filling	46.33	0.00
Jute	3.44	0.00
Aluminum	0.11	0.00
Steel Cans	0.27	0.83
Total	66.01	3.80

Table 26: Average total package weight by material type per meal. Weighed manually for 50 MK recipes evaluated in this study.

Food Waste Data

	(ounces)	
Food Category	MK Scenario	Grocery Scenario
Fruit	2.54	4.71
Vegetables		
Dark Green Vegetables	4.09	7.89
Red and Orange Vegetables	4.96	7.48
Legumes	1.85	3.40
Starchy	4.75	6.72
Other Vegetables	9.28	19.60
Grains	3.72	22.36
Protein		
Seafood	1.28	1.28
Meat	2.27	2.64
Poultry	1.32	2.01
Eggs	0.29	1.04
Nuts	0.44	2.35
Dairy	2.50	10.79
Oils	0.44	4.00
Solid Fats	0.00	0.00
Sugar	0.11	4.24
Total	39.84	100.52

Table 27: Average total food quantity by food category per meal. Weighed manually for 50 MK recipes evaluated in this study.

Grocery Scenario		
Food Category	Household Food Waste Rate	Retail Food Waste Rate
Fruit	21%	9%
Vegetables		
Dark Green Vegetables	24%	8%
Red and Orange Vegetables	24%	8%
Legumes	24%	8%
Starchy	24%	8%
Other Vegetables	24%	8%
Grains	21%	12%
Protein		
Seafood	34%	8%
Meat	24%	4%
Poultry	19%	4%
Eggs	23%	9%
Nuts	9%	6%
Dairy	21%	11%
Oils	15%	21%
Solid Fats	45%	18%
Sugar	34%	11%

Table 28: Household and retail food waste rate by food category for Grocery scenario. Based on USDA Loss Adjusted Food Availability dataset (USDA, 2010).

Grocery Scenario	
Food Category	Meal per Package Size
Fruit	1.86
Vegetables	
Dark Green Vegetables	1.93
Red and Orange Vegetables	1.51
Legumes	1.84
Starchy	1.41
Other Vegetables	2.11
Grains	6.01
Protein	
Seafood	1.00
Meat	1.16
Poultry	1.52
Eggs	3.59
Nuts	5.38
Dairy	4.32
Oils	9.03
Solid Fats	0.00
Sugar	38.40

Table 29: Weighted average meals per package size by food category for Grocery scenario. Calculated manually based on manually measured packaged weight and recipe servicing size for each food item in the 50 MK recipes in this study.

Meal Kit Scenario - Household			
Food Category	Min	Most Likely	Max
Fruit	0%	0%	77%
Vegetables			
Dark Green Vegetables	0%	0%	66%
Red and Orange Vegetables	0%	0%	47%
Legumes	0%	0%	41%
Starchy	0%	0%	29%
Other Vegetables	0%	0%	62%
Grains	0%	0%	93%
Protein			
Seafood	0%	0%	9%
Meat	0%	0%	12%
Poultry	0%	0%	16%
Eggs	0%	0%	0%
Nuts	0%	0%	62%
Dairy	0%	0%	63%
Oils	0%	0%	45%
Solid Fats	0%	0%	0%
Sugar	0%	0%	24%

Table 30: Min, most likely, and max household inedible food waste rates by food category for MK Scenario. Measured manually for 50 MK recipes evaluated in this study. The most likely value is the median in the dataset.

MK Scenario - Warehouse			
Food Category	Min	Most Likely	Max
Fruit	2%	6%	9%
Vegetables			
Dark Green Vegetables	3%	6%	8%
Red and Orange Vegetables	3%	6%	8%
Legumes	3%	6%	8%
Starchy	3%	6%	8%
Other Vegetables	3%	6%	8%
Grains	3%	6%	8%
Protein			
Seafood	3%	6%	8%
Meat	7%	6%	4%
Poultry	7%	6%	4%
Eggs	2%	6%	9%
Nuts	5%	6%	6%
Dairy	0%	6%	11%
Oils	0%	6%	21%
Solid Fats	0%	6%	18%
Sugar	0%	6%	11%

Table 31: Min, most likely, and max refrigerated warehouse food waste rates for MK Scenario. Based on a combination of Blue Apron reports on food waste in their facility and Food Agriculture Organization of the UN estimates for food waste in the processing and packaging phase of food distribution for North America and Oceania (Peters, 2016) (FAO-UN, 2011).

End of Life Material Management Data

Recycling Rate Ranges			
Material	Min	Most Likely	Max
Paper Products			
Corrugated Containers	0%	90%	100%
Magazines / Third Class Mail	0%	26%	100%
Office Paper	0%	26%	100%
Mixed Paper	0%	26%	100%
Plastics			
HDPE	0%	31%	100%
LDPE	0%	12%	100%
PET	0%	31%	100%
PS	0%	5%	100%
Mixed Plastics	0%	15%	100%
Glass Container	0%	15%	100%
Ice Pack Filling	0%	0%	0%
Jute	0%	0%	0%
Aluminum Cans	0%	39%	100%
Steel Cans	0%	71%	100%
Food	0%	0%	0%

Table 32: Minimum, most likely, and maximum recycling rates by material type. Most likely value is based on the U.S. recycling rates by material type as captured in the EPA's annual material management survey (EPA, 2016).

Composting Ranges			
Material	Min	Most Likely	Max
Food	0%	5%	100%

Table 33: Minimum, most likely, and maximum composting rates for food products. The most likely value is based on U.S. composting rates for food as captured in the EPA's annual material management survey (EPA, 2016).

Type	Portion Combusted
Paper Products	
Corrugated Containers	2%
Magazines / Third Class Mail	15%
Office Paper	15%
Mixed Paper	15%
Plastics	
HDPE	16%
LDPE	17%
PET	13%
PS	17%
Mixed Plastics	17%
Glass Container	17%
Ice Pack Filling	0%
Jute	0%
Aluminum Cans	12%
Steel Cans	6%
Food	19%

Table 34: Combustion rates for disposed materials by product type. Based on U.S. combustion rates for food as captured in the EPA's annual material management survey (EPA, 2016).

Landfill Ranges for Ice Pack Filling			
Material	Min	Most Likely	Max
Food	0%	50%	100%

Table 35: Estimated range of landfill rates for ice pack filling. While ice pack filling is soluble and can be disposed of in backyards, a range accounts for the possibility that some MK Service users may still choose to landfill the product due to convenience.

Appendix D: Analysis Results Data

Grocery

Energy (kBtu)					
Category	Grocery	Median	Min	Max	SD
Building	20.73	20.77	14.60	27.36	2.06
Food Waste	9.09				
Product Packaging	2.64	2.63	2.53	2.73	0.04
Last Mile Transportation	6.56	6.05	0.19	17.82	3.47
End of Life Management	0.24	0.24	0.23	0.26	0.01
Total (Modeled)	39.25	38.93	27.39	52.87	4.02
Emissions (Pound CO2e)					
Category	Grocery	Median	Min	Max	SD
Building	2.34	2.34	1.06	3.88	0.47
Food Waste	1.86				
Product Packaging	0.38	0.38	0.34	0.40	0.01
Last Mile Transportation	1.05	0.97	0.01	2.79	0.56
End of Life Management	0.25	0.28	-0.24	0.51	0.17
Total (Modeled)	5.88	5.84	3.62	8.58	0.76

Table 36: Total energy and emissions data for Grocery scenario

Meal Kit

Energy (kBtu)					
Category	Meal Kit	Median	Min	Max	SD
Building	5.12	4.74	0.22	15.24	2.62
Food Waste	6.01	5.95	2.81	10.79	1.18
Product Packaging	13.91	14.00	11.78	15.64	0.76
Last Mile Transportation	5.13	4.89	0.54	10.98	2.20
End of Life Management	0.78	0.78	0.36	1.21	0.16
Total (Modeled)	30.94	30.80	19.72	47.55	3.68
Emissions (Pound CO2e)					
Category	Meal Kit	Median	Min	Max	SD
Building	0.54	0.49	0.03	1.63	0.28
Food Waste	1.02	1.02	0.57	1.63	0.15
Product Packaging	2.83	2.75	1.43	5.49	0.68
Last Mile Transportation	0.84	0.81	0.09	1.80	0.36
End of Life Management	0.43	0.44	0.01	0.82	0.13
Total (Modeled)	5.65	5.61	3.07	9.18	0.84

Table 37: Total energy and emissions data for MK scenario

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